Revised 2023 and Later Model Year LightDuty Vehicle GHG Emissions Standards: Regulatory Impact Analysis

United States
Environmental Protection
Agency

Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards: Regulatory Impact Analysis

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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United States Environmental Protection Agency

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Executive Summary

This Regulatory Impact Analysis (RIA) contains supporting documentation to the Environmental Protection Agency (EPA) final rulemaking and addresses requirements in Clean Air Act Section 317. The preamble to the Federal Register notice associated with this document provides the full context for the EPA final rule, and it references this RIA throughout.

The EPA is establishing revised, more stringent national greenhouse gas (GHG) emissions standards for passenger cars and light trucks under section 202(a) of the Clean Air Act (CAA). Section 202(a) requires EPA to establish standards for emissions of air pollutants from new motor vehicles which, in the Administrator's judgment, cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. 42 U.S.C. 7521(a).

This program further revises the light-duty vehicle GHG standards previously revised by the SAFE rule and builds upon earlier EPA actions and supporting analyses that established or maintained stringent light-duty vehicle GHG emissions standards. For example, in 2012, EPA issued a final rule establishing light-duty vehicle GHG standards for model years (MY) 2017-2025,[a] which were supported in analyses accounting for compliance costs, lead time and other relevant factors.[b] That rule and its analyses also accounted for the development and availability of advanced GHG emission-reducing technologies for gasoline-fueled vehicles, which demonstrated that the standards were appropriate under section 202(a) of the CAA.[c] This final rule relies upon additional analysis that consider updated data and recent developments. Auto manufacturers are currently implementing an increasing array of advanced gasoline vehicle GHG emission reduction technologies at a rapid pace throughout their vehicle fleets. Vehicle electrification technologies are also advancing rapidly, as battery costs have continued to decline, and automakers have announced an increasing diversity and volume of zero-emission vehicle models. Additionally, in 2019, several auto manufacturers voluntarily entered into agreements with the State of California to comply with GHG emission reduction targets through MY 2026 across their national vehicle fleets (the "California Framework Agreements") that are more stringent than the previous EPA standards as revised by the SAFE rule. These developments further supported EPA's decision to reconsider and revise the previous EPA standards and to establish more stringent standards, particularly in light of factors indicating that more stringent near-term standards were feasible at reasonable cost and would achieve significantly greater GHG emissions reductions and public health and welfare benefits than the previous program. EPA has conducted outreach with a wide range of interested stakeholders, including labor unions, states, and industry as provided in E.O. 13990, as part of our regulatory development process for the revised light-duty GHG emissions standards.

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[a] EPA's model year emission standards also apply in subsequent model years, unless revised, e.g., MY 2025 standards issued in the 2012 rule also applied to MY 2026 and beyond.

[b] 77 FR 62624, October 15, 2012.

[c] Id.

The revisions to the standards are limited to MYs 2023-2026, consistent with lead time considerations under the CAA.[d] We designed the program based on our assessment that the revised standards are reasonable and appropriate and will achieve a significant level of GHG reductions for MYs 2023-2026 vehicles, with the expectation that a future, longer-term program for MYs 2027 and later will build upon these near-term standards.

Revisions to Light-duty GHG Emissions Standards

As with EPA's previous light-duty GHG programs, EPA has finalized footprint-based standards curves for both passenger cars and trucks. Each manufacturer has a unique standard for the passenger cars category and another for the truck category[e] for each MY based on the sales-weighted footprint-based CO_2 targets[f] of the vehicles produced in that MY. Figure 1 shows EPA's revised standards, expressed as average fleetwide GHG emissions targets (cars and trucks combined), projected through MY 2026. For comparison, the figure also shows the corresponding targets for the SAFE final rulemaking (FRM) and the 2012 FRM. The final fleet targets pick up from the existing SAFE FRM targets for model years 2021 and 2022, but then ramp down considerably in model year 2023, nearly reaching the 2012 FRM targets for that model year. The final fleet targets approximately parallel the 2012 FRM targets for model years 2023 and 2024, are approximately equivalent to the 2012 FRM target in model year 2025 (the last year of stringency increases in the 2012 FRM), and then decrease at a more stringent year-over-year downward slope for one additional model year, to model year 2026 (which is also the last year of stringency increases in the SAFE FRM). As with all EPA light-duty GHG rules, the targets in the last year of stringency increases would then remain at the same level for all subsequent model years unless changed by a subsequent rulemaking. Figure 1 and Table 1 present the estimates of EPA's final revised standards, again in terms of the projected overall industry fleetwide CO_2-equivalent emission compliance target levels. The industry fleet-wide estimates in Table 1 are projections based on modeling EPA conducted for the final rule, taking into consideration projected fleet mix and footprints for each manufacturer's fleet in each model year. Figure 1 and Table 2 present the projected industry fleet average year-over-year percent reductions (and cumulative reductions from 2022 through 2026) comparing the previous standards under the SAFE rule and the final, revised standards. See Chapter 2 for a full discussion of the revised standards.

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[d] Note that while only the 2023-2026 Light-duty GHG Standards are revised, as with all EPA vehicle emissions standards, the MY 2026 standards will remain in place for all subsequent MYs, unless and until the standards for future MYs are revised in a subsequent rulemaking.

[e] Passenger cars include cars and smaller cross-overs and SUVs, while the truck category includes larger cross-overs and SUVs, minivans, and pickup trucks.

[f] Because compliance is based on the full range of vehicles in a manufacturer's car and truck fleets, with lower-emitting vehicles compensating for higher-emitting vehicles, the emission levels of specific vehicles within the fleet are referred to as targets, rather than standards.

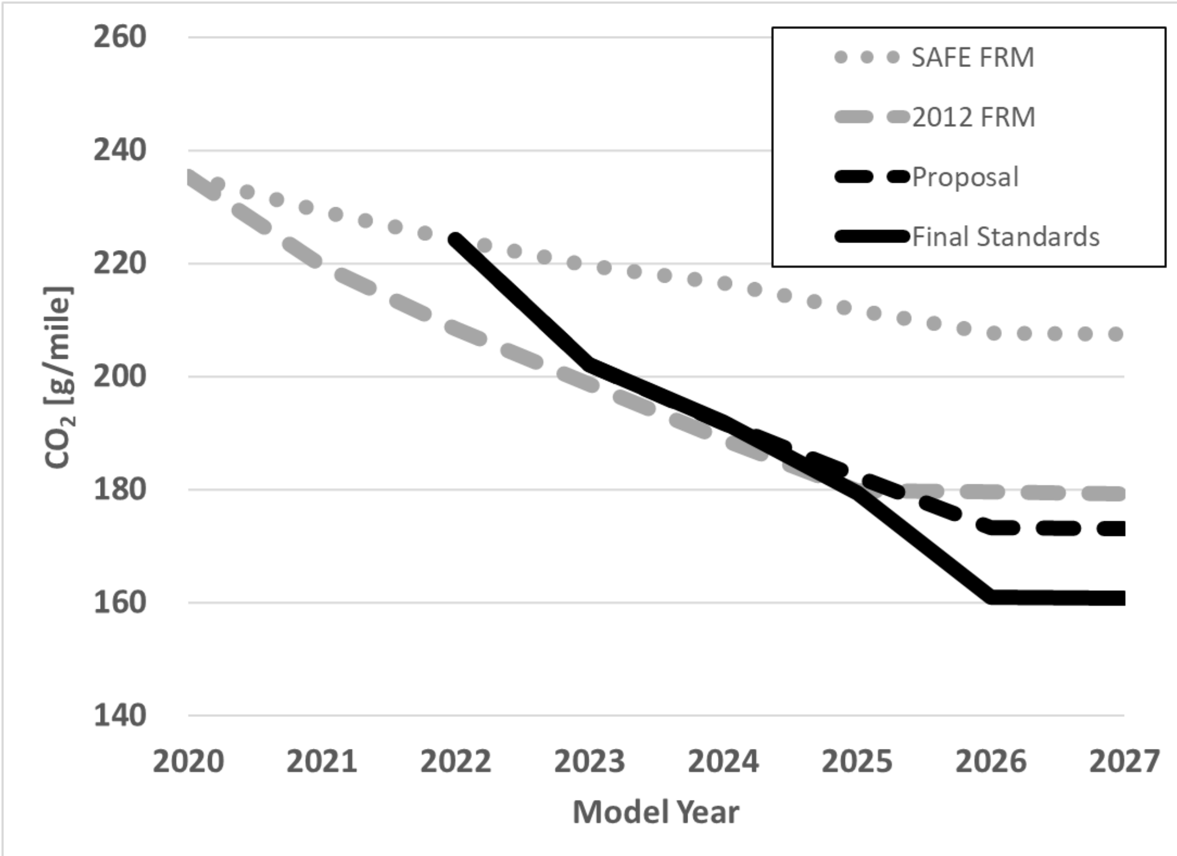

Table 1: Projected Industry Fleet-wide CO_2 Compliance Targets (grams/mi)*

Model Year	Cars CO_2 (g/mile)	Light Trucks CO_2 (g/mile)	Fleet CO_2 (g/mile)
2022 (SAFE reference)	181	261	224
2023	166	234	202
2024	158	222	192
2025	149	207	179
2026 and later	132	187	161
Total change 2022-2026	-49	-74	-63
Percent change 2022-2026	27.1%	28.4%	28.1%

*The combined car/truck CO_2 targets are a function of projected car/light truck shares, which have been updated for this final rule (MY 2020 is 44 percent car and 56 percent light trucks while the projected mix changes to 47 percent cars and 53 percent light trucks by MY 2026).

Table 2: Projected Industry Fleet Average Target Year-Over-Year Percent Reductions

	SAFE Rule			Proposed Rule			Final Rule		
	Cars	Light Trucks	Combined	Cars	Light Trucks	Combined	Cars	Light Trucks	Combined
2023	1.7%	1.7%	2.1%	8.4%	10.4%	9.8%	8.4%	10.4%	9.8%
2024	0.6%	1.5%	1.4%	4.7%	5.0%	5.1%	4.8%	4.9%	5.1%
2025	2.3%	1.7%	2.2%	4.8%	5.0%	5.0%	5.7%	7.0%	6.6%
2026	1.8%	1.6%	1.9%	4.8%	5.0%	5.0%	11.4%	9.5%	10.3%
Cumulative	6.3%	6.3%	7.4%	20.9%	23.1%	22.8%	27.1%	28.3%	28.3%

* Note the percentages shown for the SAFE rule targets have changed slightly from the proposed rule, due to the updates in our base year fleet from MY 2017 to MY 2020 manufacturer fleet data.
** These are modeled results based on projected fleet characteristics and represent percent reductions in projected targets, not the standards (which are the footprint car/truck curves), associated with that projected fleet (see Section III for more detail on our modeling results).

Compliance Incentives and Flexibilities

The existing Light-duty GHG program established in the 2010 and 2012 rules includes several key flexibilities, such as credit programs and technology incentives, including:

- Credit Averaging, Banking, and Trading (ABT) with credit carry-forward, credit carry-back, transferring of credits between a manufacturer's car and truck fleets, and credit trading between manufacturers (see Chapter 2.1.1)
- Off-cycle credits for GHG emissions reductions not captured by the test procedures used for fleet average compliance with the footprint-based standards
- Air conditioning credits for system efficiency improvements and reduced refrigerant leakage or use of low global warming potential refrigerants
- Multiplier incentives for advanced technology vehicles including electric vehicles, fuel cell vehicles, and plug-in hybrid-electric vehicles
- Full-size pick-up incentives for hybridization or GHG improvements equivalent to hybridization

EPA has finalized a limited, targeted set of extended or additional compliance flexibilities and incentives that we believe are appropriate given the stringency and lead time of the revised standards. There are four types of flexibilities/incentives, in addition to flexibilities/incentives that are already available for these MYs and that are carried over from EPA's previous regulations:

1. A limited extension of carry-forward credits generated in MYs 2017 and 2018;
2. An extension of the advanced technology vehicle multiplier credits for MYs 2023 and 2024 with a cumulative credit cap;
3. Restoration of the 2012 rule's full-size pickup truck incentives for strong hybrids or similar performance-based credit for MYs 2023 and 2024 (provisions which were removed in the SAFE rule); and
4. An increase of the off-cycle credits menu cap from 10 g/mile to 15 g/mile for MYs 2023 through 2026.

We summarize these flexibilities and incentives below and provide further detail within Sections I.B.2 and II.B.4 of the Preamble to this final rule.

The GHG program includes existing provisions initially established in the 2010 rule, which set the MY 2012-2016 GHG standards, for how credits may be used within the program. These averaging, banking, and trading (ABT) provisions include credit carry-forward, credit carry-back (also called deficit carry-forward), credit transfers (within a manufacturer), and credit trading (across manufacturers). These ABT provisions define how credits may be used and are integral to the program. The previous SAFE program limited credit carry-forward to 5 years. EPA has revised this to include a limited extension of credit carry-forward for credits generated in MYs 2017 and 2018. This revision changes the credit carry-forward time limitation for those MY credits from five to six years as shown in Table 3. For all other credits generated in MY 2016 and later, credit carry-forward remains unchanged at five years.

Table 3: Final EPA's Extension of Credit Carry-forward Provisions

MY in which Credits are Banked	MYs Credits Are Valid Under EPA's Proposed and Final Extension										
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
2016		x	x	x	x	x	■	■			
2017			x	x	x	x	x	+			
2018				x	x	x	x	x	+		
2019					x	x	x	x	x	■	
2020						x	x	x	x	x	■
2021							x	x	x	x	x

Notes:
x = Current program.
■ = Additional years proposed but not finalized.
+ = Additional years finalized.

The previous GHG program also included temporary incentives through MY 2021 that encouraged the use of advanced technologies such as electric, hybrid, and fuel cell vehicles, as well as incentives for full-size pickups using strong hybridization or technologies providing similar emissions reductions to hybrid technology. The full-size pickup incentives were originally available through MY 2025, but the SAFE rule removed these incentives for MYs 2022 through 2025. When EPA established these incentives in the 2012 rule, we recognized that they would reduce the effective stringency of the standards. However, we believed that it was worthwhile to have a limited near-term loss of emissions reduction benefits to increase the potential for far greater emissions reduction and technology diffusion benefits in the longer term. Our rationale was that the temporary regulatory incentives would help bring low emission technologies to market more quickly than an efficient market would in the absence of incentives.[g] With these same goals in mind for this program, we revised the multiplier incentives from MY 2023 and 2024 with a cap on multiplier credits and reinstated full-size pickup incentives for MYs 2023 and 2024 that had been removed from the program by the SAFE rule. These incentives are intended as a temporary measure supporting the transition to zero-emission vehicles and to provide additional flexibility in meeting the revised MY 2023-2026 standards,

[g] The 2020 EPA Automotive Trends Report. EPA-420-R-21-003 January 2021.

especially in the earlier years. For further details, see Sections I.B.2 and II.B.4 within the Preamble to the final rule.

The previous program also included credits for real-world emissions reductions not reflected on the test cycles used for measuring CO_2 emissions for compliance with the fleet average standards. There were credits in place for using technologies that reduce GHG emissions that aren't captured on EPA tests ("off-cycle" technologies) and improvements to air conditioning systems that increase efficiency and reduce refrigerant leakage. These credit opportunities did not sunset under the previous regulations and remain a part of the program through MY 2026 and beyond. EPA has revised an aspect of the off-cycle credits program to provide additional opportunities for manufacturers to generate credits by increasing the pre-defined menu credit cap from 10 to 15 g/mile for MYs 2023 through 2026. EPA has also modified some of the regulatory definitions used to determine whether a technology is eligible for the menu credits. EPA did not change the air conditioning credit elements of the light-duty GHG program.

Summary of Costs and Benefits

We estimate that this rule will result in significant present value net benefits of $120 billion to $190 billion (annualized net benefits of $6.2 billion to $9.5 billion) – that is, the total benefits far exceed the total costs of the program. Table 4 below summarizes EPA's estimates of total discounted costs, fuel savings, and other benefits. The results presented here project the monetized environmental and economic impacts associated with the revised standards during each calendar year through 2050. The program will have significant social benefits including $130 billion in climate benefits (with the average SC-GHGs at a 3 percent discount rate) and fuel savings of $150 billion to $320 billion exclusive of fuel taxes. For American drivers, who purchase fuel inclusive of fuel taxes, the fuel savings will total $210 billion to $420 billion in present-value through 2050 consisting of $51 billion to $100 billion in savings in the form of fuel taxes. With these fuel savings, consumers will benefit from reduced operating costs over the vehicle lifetime.

The benefits include climate-related economic benefits from reducing emissions of GHGs that otherwise contribute to climate change, reductions in energy security externalities caused by U.S. petroleum consumption and imports, the value of certain particulate matter-related health benefits (including premature mortality), the value of additional driving attributed to the rebound effect, and the value of reduced refueling time needed to fill up a more fuel-efficient vehicle. The analysis also includes estimates of economic impacts stemming from additional vehicle use, such as the economic damages caused by crashes, congestion, and noise (from increased rebound driving). See Chapter 10 for more information regarding these estimates.

Table 4: Monetized Discounted Costs, Benefits, and Net Benefits of the Final Program for Calendar Years through 2050 (Billions of 2018 dollars)[a,b,c,d,e]

	Present Value		Annualized Value	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Costs	$300	$180	$15	$14
Fuel Savings (exclusive of taxes)	$320	$150	$16	$12
Benefits	$170	$150	$8.6	$8.1
Net Benefits	$190	$120	$9.5	$6.2

Notes:

a Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.

b Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

c The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.

d Net benefits reflect the fuel savings plus benefits minus costs.

e Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

EPA estimates the average per-vehicle cost to meet the standards to be $1,000 in MY 2026, as shown in Table 5 below. We discuss our cost analysis in more detail in Preamble Section III and RIA Chapter 4.

Table 5 Car, Light Truck and Fleet Average Cost per Vehicle Relative to the No Action Scenario (2018 dollars)

	2023	2024	2025	2026
Car	$150	$288	$586	$596
Light Truck	$485	$732	$909	$1,356
Fleet Average	$330	$524	$759	$1,000

The final standards will achieve significant reductions in GHG emissions. As seen in Table 6 below, through 2050 the program will achieve more than 3.1 billion tons of GHG emission reductions, which is 50 percent greater emissions reductions than EPA's proposed standards.

Table 6 GHG Reductions Through 2050

Emission Impacts relative to No Action			Percent Change from No Action		
CO_2 (Million metric tons)	CH4 (Metric tons)	N2O (Metric tons)	CO_2	CH4	N2O
-3,125	-3,272,234	-96,735	-9%	-8%	-8%

Summary of the Analysis of Alternatives to the Final Rule

Description of Alternatives

Along with the finalized standards, we analyzed both a more stringent and a less stringent alternative. For the less stringent alternative, referred to as "Proposal" or "Proposed Standards", EPA assessed the coefficients of the standards proposed in the NPRM, including the advanced technology multipliers consistent with those proposed. Given the increased stringency of the final standards compared to the proposal for MYs 2025 and 2026, EPA believes the proposal represents an appropriate less stringent alternative for comparison.

For the more stringent alternative, referred to as "Alternative 2 minus 10", EPA assessed Alternative 2 from our proposed rule with an additional 10 grams/mile increased stringency in MY 2026, per our request for public comment on this option. This alternative is more stringent than the final standards in MYs 2023 and 2024. For this alternative, EPA used the coefficients from Alternative 2 in the proposed rule for MYs 2023 through 2025, with the standards increasing in stringency by an additional 10 grams/mile compared to Alternative 2 standards in MY 2026. The Alternative 2 minus 10 standards are the same as the final standards for MYs 2025 and 2026 and differ from the final standards in MYs 2023 and 2024.

EPA is finalizing several changes to program flexibilities. Further details regarding program flexibilities can be found in Sections I.B.2 and II.B.4 of the Preamble to this Final Rule. Flexibility changes, for the purpose of analyzing alternatives, are applied to Alternative 2 minus 10 as well as the final standards, as shown in Table 7 below, including the applicability of flexibilities to the final standards and alternatives being analyzed.

Table 7: Applicability of Program Provisions to the Final Standards, and the Proposal and Alternative 2 minus 10 Standards

Provision	Final Standards	Proposal	Alternative 2 minus 10
Extension of credit carry-forward	MYs 2017 and 2018	MYs 2016-2020	MYs 2017 and 2018
Advanced technology incentive multipliers	MYs 2023-2024, with cap	MYs 2022-2025 with cap	No
Increase of off-cycle menu cap from 10 to 15 g/mile	Yes, for MYs 2023-2026	Yes, beginning in MY 2020	Yes, for MYs 2023-2026
Reinstatement of full-size pickup incentive for strong hybrids or equivalent technologies	Yes, for MYs 2023 and 2024	Yes, for MYs 2022-2025	Yes, for MYs 2023 and 2024
Note: EPA's technical analysis, presented in Chapter 4, consists of model runs using a model capable of reflecting some but not all of these provisions. The modeling includes consideration of advanced technology incentive multipliers for the proposed and final standards but not for the Alternative. The model runs also include the 15 grams per mile off-cycle menu cap as appropriate given the standards or targets to which a fleet being modeled is complying. Not included in the model runs are the full-size pickup truck technology incentive credit or the extension of the emissions credit carry-forward.			

The fleet average targets for the two alternatives compared to the final standards are provided in Table 8. As discussed in detail in Chapter 2.3.3, there has been a proliferation of recent announcements from automakers signaling a rapidly growing shift in investment away from internal-combustion technologies and toward high levels of electrification. EPA has also heard from a wide range of stakeholders over the past several months, including but not limited to the automotive manufacturers and the automotive suppliers, that the significant investments being made now to develop and launch new EV product offerings and in the expansion of EV charging infrastructure could enable higher levels of EV penetration to occur in the market place by the model year 2026 time frame than we have projected in this rule for the revised model year 2026 standards.

Table 8: Projected Fleet Average Target Levels for Final Standards and Alternatives (CO_2 grams/mile) *

Model Year	Final Standards Projected Targets	Proposal Projected Targets	Alternative 2 minus 10 Projected Targets
2021**	229	229	229
2022**	224	224	224
2023	202	202	198
2024	192	192	189
2025	179	182	180
2026	161	173	161

* Targets shown are modeled results and, therefore, reflect fleet projections impacted by the underlying standards. For that reason, slight differences in targets may occur despite equality of standards in a given year.
** SAFE rule targets included here for reference.

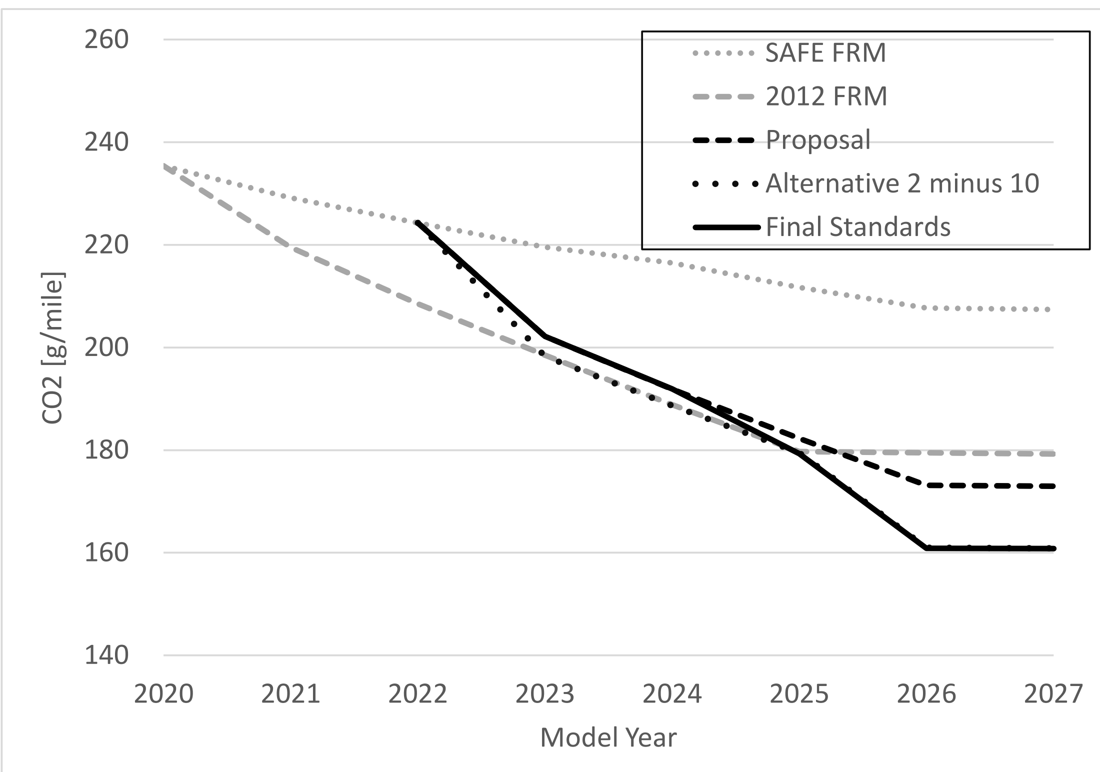

Figure 2: Final Standards Fleet Average Targets Compared to Alternatives

As shown in Figure 2, the range of alternatives that EPA analyzed differ from the final standard targets in any given model year in 2023-2025 by 3 to 4 g/mile, and in model year 2026 by 12 g/mi. EPA believes the final standards are reasonable and appropriate considering the relatively limited lead time for the standards (especially for model years 2023-2024), our assessment of feasibility, the existing automaker commitments to meet the California Framework (representing about 28 percent of the auto market), the standards adopted in the 2012 rule, submitted public comments, the reasonableness of our estimated costs per vehicle, and the need to reduce GHG emissions. EPA provides further discussion of the feasibility of the revised standard and alternatives and the selection of the revised standards within Chapter 2.2.2. The analysis of costs and benefits of the Proposal and Alternative 2 minus 10 standards is shown in the Chapters 4, 5, 6, and 10.

Summary of Costs and Benefits of the Alternatives

EPA estimates that the less stringent (Proposal) alternative would result in significant present value net benefits of $82 billion to $130 billion (annualized net benefits of $4.2 billion to $6.4 billion) – that is, the total benefits would far exceed the total costs of the program. Table 9 below summarizes EPA's estimates of total discounted costs, fuel savings, and benefits for the Proposal. The results presented here project the monetized environmental, public health and economic impacts associated with the Proposal standards during each calendar year through 2050. The Proposal would have significant social benefits including $83 billion in climate benefits (with the average SC-GHGs at a 3 percent discount rate) and fuel savings of $100 billion to $210 billion exclusive of fuel taxes. For American drivers, who purchase fuel inclusive of fuel taxes, the fuel savings would total $130 billion to $270 billion through 2050. With these fuel savings, consumers would benefit from reduced operating costs over the vehicle lifetime.

The benefits include climate-related economic benefits from reducing emissions of GHGs that otherwise contribute to climate change, reductions in energy security externalities caused by U.S. petroleum consumption and imports, the value of certain particulate matter-related health benefits (including premature mortality), the value of additional driving attributed to the rebound effect, and the value of reduced refueling time needed to fill up a more fuel-efficient vehicle. The analysis also includes estimates of economic impacts stemming from additional vehicle use, such as the economic damages caused by crashes, congestion, and noise (from increased rebound driving). See the Chapters 4, 5, 6, and 10 for more information regarding these estimates.

Table 9: Monetized Discounted Costs, Benefits, and Net Benefits of the Proposal Standards for Calendar Years through 2050 (Billions of 2018 dollars)[a,b,c,d,e]

	Present Value		Annualized Value	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Costs	$190	$110	$9.8	$9.2
Fuel Savings	$210	$100	$11	$8.2
Benefits	$110	$96	$5.6	$5.3
Net Benefits	$130	$82	$6.4	$4.2

Notes:
[a] Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.
[b] Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.
[c] The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.
[d] Net benefits reflect the fuel savings plus benefits minus costs.
[e] Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

We estimate that Alternative 2 minus 10 standards would result in significant present value net benefits of $120 billion to $180 billion (annualized net benefits of $5.7 billion to $9.2 billion) – that is, the total benefits would far exceed the total costs of the program. Table 10 below summarizes EPA's estimates of total discounted costs, fuel savings, and benefits for Alternative 2 minus 10. The results presented here project the monetized environmental and economic impacts associated with the final standards during each calendar year through 2050. Alternative 2 minus 10 would have significant social benefits including $130 billion in climate benefits (with the average SC-GHGs at a 3 percent discount rate) and fuel savings of $160 billion to $320 billion exclusive of fuel taxes. For American drivers, who purchase fuel inclusive of fuel taxes, the fuel savings would total $210 billion to $430 billion through 2050. With these fuel savings, consumers would benefit from reduced operating costs over the vehicle lifetime.

The benefits include climate-related economic benefits from reducing emissions of GHGs that otherwise contribute to climate change, reductions in energy security externalities caused by U.S. petroleum consumption and imports, the value of certain particulate matter-related health benefits (including premature mortality), the value of additional driving attributed to the rebound effect, and the value of reduced refueling time needed to fill up a more fuel-efficient vehicle. The analysis also includes estimates of economic impacts stemming from additional vehicle use, such as the economic damages caused by crashes, congestion, and noise (from increased rebound driving). See the Chapters 4,5,6, and 10 for more information regarding these estimates.

Table 10: Monetized Discounted Costs, Benefits, and Net Benefits of Alternative 2 minus 10 for Calendar Years through 2050 (Billions of 2018 dollars)[a,b,c,d,e]

	Present Value		Annualized Value	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Costs	$320	$190	$16	$15
Fuel Savings	$320	$160	$16	$13
Benefits	$170	$150	$8.9	$8.3
Net Benefits	$180	$120	$9.2	$5.7

Notes:
[a] Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.
[b] Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.
[c] The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.
[d] Net benefits reflect the fuel savings plus benefits minus costs.
[e] Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

Summary of the Costs and Benefits of the Final Revised Standards Compared to the Alternatives

Table 11 through Table 12 provide summaries of the final rule's costs and benefits compared to the costs and benefits of the two alternatives that were analyzed. The benefits include climate-related economic benefits from reducing emissions of GHGs that otherwise contribute to climate change, reductions in energy security externalities caused by U.S. petroleum consumption and imports, the value of certain particulate matter-related health benefits (including premature mortality), the value of additional driving attributed to the rebound effect, and the value of reduced refueling time needed to fill up a more fuel-efficient vehicle. The analysis also includes estimates of economic impacts stemming from additional vehicle use, such as the economic damages caused by crashes, congestion, and noise (from increased rebound driving). See Chapters 4, 5, 6 and Chapter 10 for more information regarding these estimates. Net benefits for the Final Revised Standards exceed those of either the Proposal or Alternative 2 minus 10 when using a 3 percent discount rate. At a 7 percent discount rate, the net benefits for the Final Standards are approximately equivalent to Alternative 2 minus 10 and exceed those of the Proposal.

Table 11: Present Value Monetized Discounted Costs, Benefits, and Net Benefits of the Final Program and Alternatives for Calendar Years through 2050 (Billions of 2018 dollars)[a,b,c,d,e]

	3% Discount Rate			7% Discount Rate		
	Final Standards	Proposal	Alternative 2 minus 10	Final Standards	Proposal	Alternative 2 minus 10
Costs	$300	$190	$320	$180	$110	$190
Fuel Savings	$320	$210	$320	$150	$100	$160
Benefits	$170	$110	$170	$150	$96	$150
Net Benefits	$190	$130	$180	$120	$82	$120

Notes:
[a] Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.
[b] Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.
[c] The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.
[d] Net benefits reflect the fuel savings plus benefits minus costs.
[e] Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

Table 12: Annualized Monetized Discounted Costs, Benefits, and Net Benefits of the Final Program and Alternatives for Calendar Years through 2050 (Billions of 2018 dollars)a,b,c,d,e

	3% Discount Rate			7% Discount Rate		
	Final Standards	Proposal	Alternative 2 minus 10	Final Standards	Proposal	Alternative 2 minus 10
Costs	$15	$9.8	$16	$14	$9.2	$15
Fuel Savings	$16	$11	$16	$12	$8.2	$13
Benefits	$8.6	$5.6	$8.9	$8.1	$5.3	$8.3
Net Benefits	$9.5	$6.4	$9.2	$6.2	$4.2	$5.7

Notes:

[a] Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.

[b] Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

[c] The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.

[d] Net benefits reflect the fuel savings plus benefits minus costs.

[e] Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

RIA Chapter Summary

This document contains the following Chapters:

Chapter 1: Background

This chapter provides background on previous Agency actions with respect to the light-duty vehicle GHG emissions program and summaries of previous EPA analyses.

Chapter 2: Technology Feasibility, Effectiveness, Costs, and Lead-time

This chapter summarizes the revisions to the model year 2023 and later light-duty vehicle GHG standards. It also includes a summary of GHG compliance incentives and flexibilities and discusses technological feasibility and manufacturer's lead-time considerations.

Chapter 3: Economic and Other Key Inputs

This chapter provides EPA's analyses of rebound effects, energy security impacts, the social cost of greenhouse gases, and the costs associated with congestion and noise.

Chapter 4: Modeling GHG Compliance

This chapter discusses the analytical methodology used to model GHG emissions compliance of the light-duty vehicle fleet with the standards and then summarizes the resulting estimated compliance costs and associated technology pathways necessary to comply with the revisions to the model year 2023 and later GHG standards.

Chapter 5: Projected Impacts on Emissions, Fuel Consumption, and Safety

This chapter documents EPA's analysis of the emission, fuel consumption and safety impacts of the emission standards for light-duty vehicles. Light-duty vehicles include passenger vehicles such as cars, sport utility vehicles, vans, and pickup trucks. Such vehicles are used for both commercial and personal uses and are significant contributors to the total United States (U.S.) GHG emission inventory.

Chapter 6: Vehicle Program Costs and Fuel Savings

In this chapter, EPA presents our estimated costs associated with the vehicle program. This includes summaries of the vehicle level costs associated with new technologies expected to be added to meet the model year 2023 and later GHG standards. The analysis also provides costs associated with congestion, noise, fatalities and non-fatal crashes.

Chapter 7: Non-GHG Health and Environmental Impacts

In this chapter we discuss the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants will not be directly regulated by the revisions to the GHG standards, but the standards will affect emissions of these pollutants and precursors.

Chapter 8: Vehicle Sales, Employment, and Affordability and Equity Impacts

This chapter presents the methodology and analytical results for EPA's modeling of vehicle sales and employment impacts. It also includes an analysis of affordability and the potential impacts on lower-income households, the used vehicle market, access to credit, and the low-priced new vehicle segment.

Chapter 9: Small Business Flexibilities

This chapter discusses the flexibilities provided to small businesses under the revisions to the model year 2023 and later light-duty GHG standards.

Chapter 10: Summary of Costs and Benefits

This Chapter presents a summary of costs, benefits, and net benefits of the program and the alternatives.

Chapter 1: Background

The analyses for this final rule represent the sixth time that EPA has analyzed the feasibility and cost associated with meeting stringent GHG standards in the 2021/2022 through 2025/2026 timeframe. Previous analyses include the 2012 FRM, the 2016 Draft Technical Assessment Report (DTAR), the 2016 MTE Proposed Determination, the 2018 analysis performed to update the MTE analyses for the previous administration, and the proposal from earlier this year. Through these six analyses EPA has applied five different initial fleets and updated critical inputs such as fuel costs. We have continued to develop our cost and effectiveness assessments and we have refined our analytical tools, including the CAFE Compliance and Effects Modeling System (CCEMS), for the final rule. For more details regarding EPA's use of CCEMS for the final rule analysis, please see Chapter 4. As discussed below and summarized in Figure 1-1, the results have been remarkably consistent when comparing previous EPA analyses to the analysis for the final rule summarized in Chapter 4.

In 2012, EPA established greenhouse gas (GHG) emissions standards for model year 2017 and later new passenger cars, light-duty trucks, and medium-duty passenger vehicles.[1] The program was projected to reduce GHG emissions from model year 2025 light-duty vehicles by 50 percent relative to model year 2010 vehicles.

As part of the 2012 Final Rule, EPA made a regulatory commitment to conduct a Midterm Evaluation (MTE) of the standards for MY 2022-2025. As a part of this process, EPA examined a wide range of factors, such as developments in powertrain technology, vehicle electrification, vehicle mass reduction and potential vehicle safety impacts, the penetration of fuel efficient technologies in the marketplace, consumer acceptance of fuel efficient technologies, trends in fuel prices and the vehicle fleet, employment impacts, and many other factors.

The 2012 Final Rule established three formal steps for the MTE process:

1. Draft Technical Assessment Report (TAR) to be issued jointly with the National Highway Traffic Safety Administration (NHTSA) and the California Air Resources Board (CARB) with opportunity for public comment. This was completed in July 2016.
2. The EPA Administrator was to make a Proposed Determination with opportunity for public comment. The Proposed Determination was completed in November 2016.
3. The EPA Administrator was to make a final determination with regard to whether the standards remained appropriate or should be changed no later than April 1, 2018. The Final Determination was completed in January 2017 and the Revised Final Determination was completed in April 2018.

There were opportunities for public input on the Draft TAR and the Proposed Determination and a formal Response to Comments document was issued by EPA along with the Final Determination in January 2017.

A timeline for the 2012 final rule, the MTE, and the SAFE rule is summarized within Figure 1-1. Despite the extensive EPA economic, scientific, and engineering analyses made publicly available as part of the MTE process through the January 2017 Final Determination, and the availability of an updated 2018 EPA MTE Analysis completed in January 2018, these prior EPA analyses were not used as the basis of the Agency's March 2017 MTE Reconsideration, April 2018 Revised MTE Final Determination or the proposed or final SAFE rules.

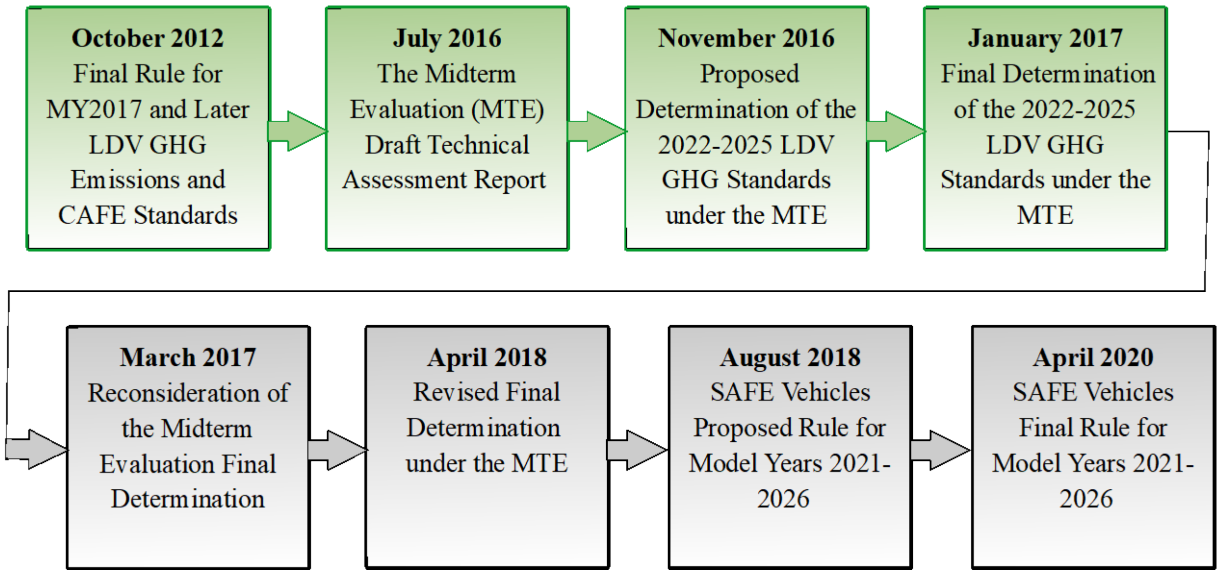

Figure 1-1: Regulatory Timeline for the Model Year (MY) 2017 and Later Light-duty Vehicle (LDV) Greenhouse Gas (GHG) Emissions Standards, the Midterm Evaluation, and Safe Rule. The top row represents Agency actions that used EPA analyses as the basis.

1.1 Summary of 2012 Final Rulemaking

1.1.1 Light-duty Vehicle GHG Emissions Standards

The 2017 and later light-duty vehicle GHG standards were established within the 2012 Final Rulemaking (2012 FRM) based upon CO_2 emissions-footprint curves, where each vehicle has a different CO_2 emissions compliance target depending on its characteristic footprint (i.e., the area contained within the vehicle wheelbase and track width). In general, vehicles with a larger footprint have higher corresponding vehicle CO_2 emissions standards. As a result, the burden of compliance within this program was distributed across all vehicles and all manufacturers and each manufacturer would have its own fleet-wide standard that reflects the vehicles it chooses to produce. The program also provided a wide range of credit programs and flexibilities for manufacturers to meet 2017 and later GHG standards.

Table 1-1 shows the projected fleet-wide CO_2 emission targets under the footprint-based approach used in the 2012 FRM. Passenger car CO_2 emission levels were projected to increase in stringency from 212 to 143 grams per mile (g/mi) between MY s 2017 and 2025. Similarly, fleet-wide CO_2 emission levels for trucks were projected to increase in stringency from 295 g/mi in MY 2017 to 203 g/mi in MY 2025. EPA projected that the average light-duty vehicle (combined car and truck) tailpipe CO_2 compliance level in MY 2017 would be 243 g/mi, phasing down by MY 2025 to 163 g/mi. These projected targets in the first three rows include the effects of credits and flexibilities. In contrast, the final row provides the actual tailpipe emissions achieved by manufacturers for 2016-2019 based on certification data and excludes the effects of credits and flexibilities.

Table 1-1: Projected Fleet-Wide Emissions Compliance Targets under the Footprint-Based CO_2 Standards in the 2012 FRM

	2016 base	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger Cars (g/mi)	225	212	202	191	182	172	164	157	150	143
Light Trucks (g/mi)	298	295	285	277	269	249	237	225	214	203
Combined Cars & Trucks (g/mi)	250	243	232	222	213	199	190	180	171	163
Actual Tailpipe CO_2**, Cars & Trucks (g/mi)**	285	284	280	282						

Notes:
Actual Tailpipe CO_2 adapted from the 2020 EPA Automotive Trends Report.[2]

The difference between actual tailpipe CO_2 emissions and the projected standards is due to not only the credits and flexibilities, but also the difference between the projected car/truck sales mix at the time of the 2012 FRM, and the actual sales mix for each model year. The 2012 FRM projected car sales greater than 60 percent for all model years. Table 1-2 shows the projected sales mix from the original rule, the actual sales mix achieved, and the effective increase in industry standards (in g/mi) for years 2016-2019 due solely to the increase in truck sales share. For example, the combined standard of 222 g/mi projected for 2019 MY increased by 17 g/mi - to 239 g/mi - primarily due to the 44 percent and 56 percent sales shares of passenger vehicles and light trucks, respectively.[a]

Table 1-2: Projected vs. Actual Car/Truck Sales Share, 2016-2019 Model Years

	2016 base	2017	2018	2019
Proj. Passenger Car Share	66%	63%	64%	64%
Proj. Light Truck Share	34%	37%	36%	36%
Actual Passenger Car Share	55%	53%	48%	44%
Actual Light Truck Share	45%	47%	52%	56%
Car/Truck Shift Effect on Stds. (g/mi)	+8	+8	+13	+17

Figure 1-2 and Figure 1-3 show the vehicle footprint vs. CO_2 emissions standards curves for cars and trucks, respectively, from the 2012 FRM. For passenger cars, the CO_2 compliance values associated with the footprint curves declined on average by approximately 5 percent per year from the MY 2016 projected passenger car industry-wide compliance level through MY 2025. To separately address GHG compliance challenges faced while preserving the utility of light-duty trucks (e.g., towing and payload capabilities), the GHG standards in the 2012 FRM provided a lower annual rate of improvement for light-duty trucks during the initial years of the program. The average annual rate of CO_2 emissions reduction in MYs 2017 through 2021 were 3.5 percent per year, increasing to 5 percent per year for MYs 2022 through 2025.

[a] While there are other factors which further increased the standards (such as slight growth in average footprint since 2012, which increases the standards by another 4 g/mi), the most significant effect is seen in the difference in car/truck sales mix.

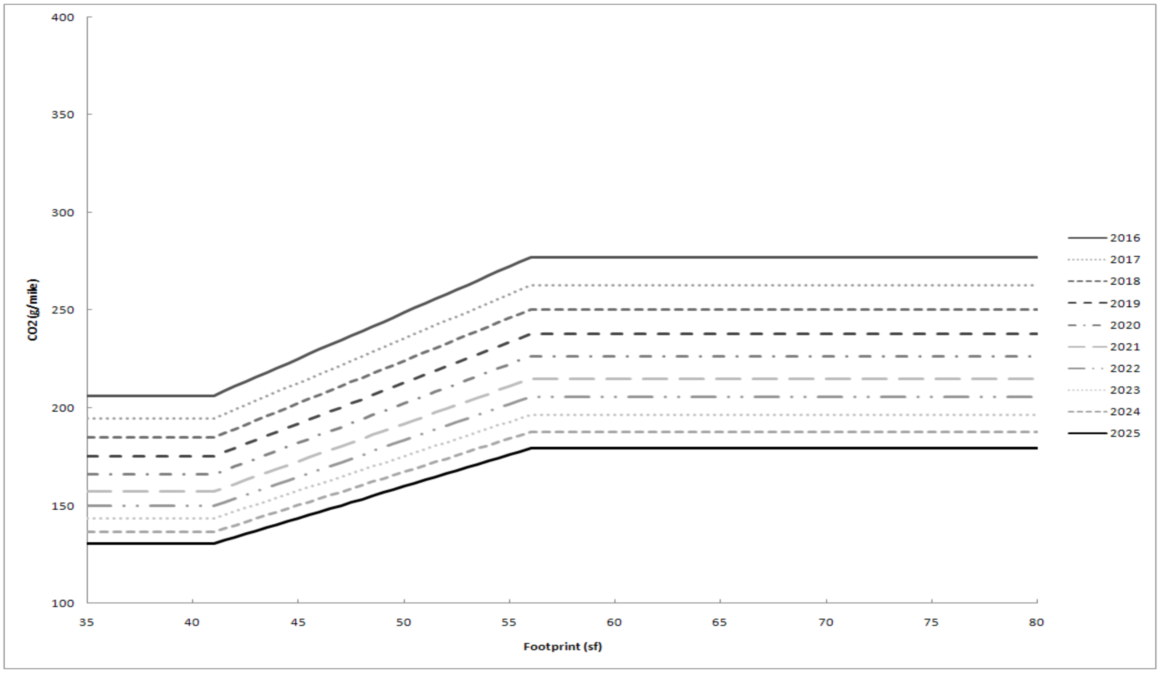

Figure 1-2: 2012 FRM Footprint Curves for Passenger Car CO_2 (g/mile) Standards

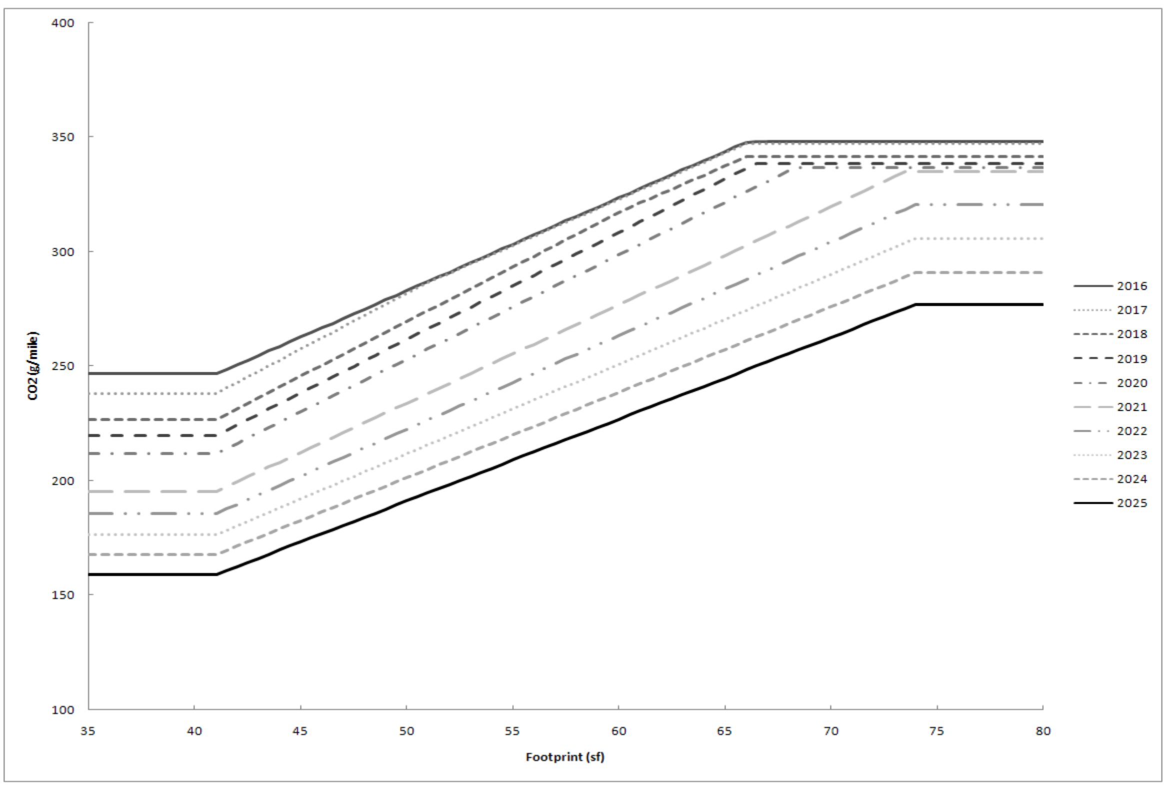

Figure 1-3: 2012 FRM Footprint Curves for Light-duty Truck CO_2 (g/mile) Standards

1.1.2 Flexibilities

EPA created flexibilities to ensure manufacturers could comply with the light-duty vehicle GHG standards. Manufacturers create product plans with the goal of full compliance with EPA regulations, however these product plans span many years and the flexibility to both bank credits some years (over comply) and create debits (under comply) is a key flexibility within many EPA regulations. Credit programs allow manufacturer to phase in new technologies during product redesigns and new product introductions instead of redesigning all vehicles to comply at once. Also, when executing product plans to meet our standards, manufacturers may need to respond to changes in fuel prices, changes in consumer demand, and parts shortages such as the recent semiconductor chip shortage[3] that directly affect what manufacturers can build. EPA has anticipated that manufacturers would need, and would take advantage of, program flexibilities within its light-duty GHG programs. This includes both credits and incentives, such as car/truck credit transfers, air conditioning credits, off-cycle credits, advanced technology vehicle multipliers, intermediate volume manufacturer lead-time provisions, and hybrid and performance-based incentives for full size pick-up trucks. See the 2017-2025 Preamble section III.C (EO12866 2017-2025 GHG-CAFE Standards_2060-AQ54_FRM_FRN_20120827_Final) for an extended discussion of these credits.

1.2 2016-2018 Midterm Evaluation of 2021-2025 Light-duty Vehicle GHG Standards

The Draft Technical Assessment Report (TAR), issued jointly by EPA, NHTSA, and CARB for public comment, was the first formal step in the MTE process.[4,5] A wide range of technical and economic issues relevant to the light-duty GHG emissions standards for MY 2022-2025 were examined and shared with the public within the Draft TAR. The analyses contained within the approximately 1,200 pages of the Draft TAR and the subsequent public comments received on the Draft TAR informed the EPA's development of the Proposed Determination (PD)[6,7] and the Final Determination (FD).[8,9] The primary conclusions of the Draft TAR were:

- A wider range of technologies exist for manufacturers to use to meet the MY 2022-2025 standards at costs similar to, or lower than, those projected in the 2012 rule;
- Advanced gasoline vehicle technologies will continue to be the predominant technologies, with modest levels of strong hybridization and very low levels of full electrification (plug-in vehicles) needed to meet the standards;
- The car/truck mix reflects updated consumer trends that are informed by a range of factors including economic growth, gasoline prices, and other macro-economic trends. However, as the standards were designed to yield improvements across the light-duty vehicle fleet, irrespective of consumer choice, updated trends are fully accommodated by the footprint-based standards.

The analyses from the Draft TAR were further updated and included as part of an approximately 700-page Technical Support Document[10] (TSD) released in conjunction with the PD and referenced within the FD. Key updates within the TSD included:

- Use of the fuel prices, vehicle sales volumes, and car/truck mix from the 2016 Energy Information Administration's Annual Energy Outlook (AEO2016)[11]
- Use of MY 2015 for the base year vehicle fleet

- Changes to EPA's vehicle simulation model to include the most recent data on technology effectiveness from the EPA vehicle benchmarking testing program and other sources
- Changes to battery costs for electrified vehicles based upon updated data from the Argonne National Laboratories (ANL) Battery Performance and Cost (BatPaC) model
- Building in additional quality assurance checks of technology effectiveness estimates
- Changes to vehicle class definitions for effectiveness modeling and a greater resolution of vehicle types to provide more accuracy and precision in representing technology cost and effectiveness for the future vehicle fleet
- Better accounting for tire and aerodynamic improvements in the base year vehicle fleet

The Administrator's November 2016 Proposed Determination was the following:

1. The MY 2022-2025 light-duty GHG standards are feasible
2. The standards will achieve significant CO_2 and oil reductions
3. The standards will provide significant benefits to consumers and the public
4. The auto industry is thriving and meeting the standards more quickly than required
5. Continued reductions in CO_2 emissions are essential to help address the threat of climate change

The Administrator also determined that there was ample evidence that supported strengthening the standards; however, she chose not to propose revising the levels of the GHG standards finalized in 2012. Comments received on the Draft TAR were addressed as part of a formal response to comments within the appendices of the TSD. [12] Comments on the PD and TSD were addressed within a separate Response to Comments Document released as part of the FD.[13]

The Administrator's January 2017 Final Determination was:

1. The MY 2022-2025 standards remain appropriate under section 202(a)(1) of the Clean Air Act
2. The standards are feasible at reasonable cost, without need for extensive electrification
3. The standards will achieve significant CO_2 and oil reductions
4. The standards will provide significant benefits to consumers and to the public
5. The auto industry is thriving and meeting the standards more quickly than required

1.2.1 Updated EPA 2018 MTE Analysis

EPA completed an analysis in January 2018 that further updated the analyses from the TSD.[14] Although conducted by EPA as part of the MTE and to inform an anticipated SAFE NPRM, the updated EPA analysis was not used as part of the revised Final Determination of April 2018, the SAFE NPRM, or the SAFE FRM. The following updates to the November 2016 TSD were included within EPA's updated January 2018 MTE analysis:

1.2.1.1 Updated Base Year Fleet Data:

The base year vehicle fleet was updated from MY 2015 to MY 2016. The EIA AEO sales projections, car and truck percentages within the fleet, and fuel prices were updated to AEO2017.[15] The OEM and vehicle class market share projections were updated using data purchased from IHS Markit, Ltd. Improvements were also implemented in EPA's ALPHA vehicle model and OMEGA compliance model to better characterize technologies within the base year fleet. The improvements included conducting ALPHA vehicle model runs for each vehicle configuration in the base year (road loads; engine, transmission, and accessory models) and confirming model alignment with CO_2 from EPA vehicle emissions certification data.

The resolution of technology characterization was improved within EPA's ALPHA vehicle model and OMEGA GHG compliance model via the following changes:

- Increased number of engine maps for turbocharged/downsized engines (i.e., 3 different engine maps vs. 1 for TSD)
- Increased number of engine maps to represent port-fuel-injected (PFI) and gasoline direct injection (GDI) engines (2 different engine maps each vs. 1 each for the TSD)
- Use of fleet-wide technology characterization to characterize the GHG performance of the 2016 fleet based primarily on certification data submitted by manufacturers to EPA’s VERIFY Database

Additional data was also obtained from EPA's Test Car Database and technical specifications that were not available in either the EPA VERIFY or Test Car databases (e.g. curb weight, dimensions, power steering type) were obtained via other public and commercially available sources of vehicle data such as Edmunds.com©, Wards Automotive (Penton©) and AllData Repair (AllData LLC©). Further details of the 2016 base year fleet characterization can be found in Bolon et al.[16]

1.2.1.2 Updated Fuel Price and Fleet Projections

Future fuel prices were updated to reflect AEO2017 projections.[15] Updated fleet volume and car/truck percentage projections were based on preliminary AEO2018 projections and updated IHS Markit forecasting.[17]

1.2.1.3 Other Updates to the ALPHA Vehicle Model

ALPHA modeling process improvements were put into place to implement cloud computing and improve computational efficiency. This allowed full combinatorial modeling of vehicle technology packages, including all combinations of engines, transmissions, accessories and road loads. The introduction of full combinatorial modeling allowed replacement of the Lumped Parameter Model (LPM) previously used within the OMEGA model with peer-reviewed response surface equations (RSEs) based entirely on ALPHA modeling. Under this approach, packages applied to future vehicles contained only the technology combinations reflected within ALPHA runs. This also eliminated any manual calibration of the LPM.

Mass reduction (MR) was applied in predefined steps based on the amount of MR required to move a vehicle into a new estimated test weight (ETW) bin. Mass reduction in passenger cars was thus not constrained by lower curb weight limits as was done for the previous TSD safety analysis.

BEVs, PHEVs and HEVs were mapped into unique vehicle types rather than being mapped into ICE vehicle types. The total number of vehicle types increased to 42 from the 29 vehicle types used within the TSD analysis, which allowed for greater granularity in both cost and effectiveness calculations.

1.2.1.4 Updates to the Technologies Considered and Technology Effectiveness

Additional technologies were used in the updated analysis that were not used within the TSD to better reflect recent vehicle product introductions. Effectiveness for engine technologies was also updated based on EPA engine and chassis dynamometer benchmarking. Updates included:

- Addition of a new, dynamically-controlled cylinder deactivation technology (deacFC)[18] based on vehicle benchmarking of Tula's Dynamic Skip Fire system, with greater effectiveness than traditional fixed cylinder deactivation (deacPD), although at higher costs due to the necessity for deactivation hardware for each cylinder
- Addition of a 2nd generation turbocharged downsized engine package based on EPA benchmark testing of the Honda L15B7 1.5L turbocharged, direct-injection engine[19]
- ALPHA modeling of 12V Start-Stop and 48V Mild Hybrids for every combination of engine/trans/vehicle class instead of using constant effectiveness for these technologies applied to each vehicle class within the TSD
- Use of an engine map for Atkinson (ATK2+CEGR) technology based on EPA benchmark testing of the MY 2018 Camry 2.5L A25A FKS engine[18] in place of using developmental engine test data and GT-POWER engine modeling within the TSD
- Updates to both aerodynamic drag technologies and other road-load reducing technologies[20]

1.2.1.5 Updates to Cost Analysis

A significant number of updates were included within the cost analysis. This included updates to the costs of vehicle electrification and other technology, some changes to indirect costs, and use of a 2016 dollar basis in order to be consistent with AEO2017. The changes to the cost analysis relative to the TSD included:

- Use of an updated ANL BatPaC model (BatPaC Version 3.1, 9 October 2017) as the basis for BEV, PHEV, HEV and mild HEV battery costs
- The learning curves for battery costs were adjusted to ensure consistency between BatPaC and OMEGA
- Non-battery BEV and PHEV costs were updated based on more recent teardown data from California Air Resources Board, UBS, and other references.[21,22,23]
- Level 2 home charging costs were updated based on data provided by the California Air Resources board on the cost of electric vehicle service equipment (EVSE).[24]
- BEV/PHEV battery and non-battery integration efforts were changed within OMEGA to a "medium complexity" as opposed to the "high complexity" used in the TSD, resulting in application of a reduced indirect cost markup
- Some additional cost savings were applied for BEVs since they did not need to add additional technology to comply with light-duty Tier 3 criteria pollutant emissions standards. Such costs were found to have been applied to BEVs within the TSD.

- Markups on emerging and future technologies remained at near-term levels through 2025 instead of using near-term levels through 2018 or 2024 as was done in the TSD
- LUB2 & EFR2 were added as incremental technologies to LUB1 and EFR1 in OMEGA and both LUB1 and EFR1 were included in all base year Exemplar vehicles.
- Cooled EGR costs were changed to a single EGR loop when applied to ATK2 engines. Previous Cooled EGR costs had assumed a higher cost low-pressure/higher pressure dual loop system for application to highly boosted (27-bar BMEP) turbocharged engines no longer used within the analysis.

1.2.1.6 Updated Sensitivity Analyses

The range of sensitivities analyzed within the OMEGA model for the Updated EPA 2018 MTE Analysis included:

- AEO2016 central, high, and low fuel price scenarios[11,b]
- No additional mass reduction beyond what existed in MY 2016 base year fleet
- Technology adoption for 20 percent of trucks constrained to 2021 standards level
- Limiting the adoption of advanced, non-turbo engine technology to 10 percent of fleet
- No new adoption of advanced transmission technologies
- No new adoption of advanced turbocharged/downsized engines
- Added consideration of credit trading between manufacturers
- No car-truck credit transfers within a manufacturer’s fleet

1.2.2 Comparison of Analytical Results Between the 2012 FRM and the MTE

Table 1-3 provides a comparison of MY 2025 light-duty vehicle fleet-average technology penetrations and per-vehicle costs for the central analytical case from the 2012 FRM and for central analytical cases and sensitivity analyses for the Draft TAR, TSD, and EPA's Updated 2018 Analysis. Although EPA is finalizing new standards for MY's 2023 through 2026, a comparison of the CEMMS analytical results for the final MY 2025 and MY 2026 standards (see RIA Chapter 4.1.2) shows remarkable consistency with analytical results over the last 10 years. Figure 1-4 shows a graphical representation comparing per vehicle costs for the same 2012 through 2018 EPA analyses. Table 1-4 compares the fuel prices, assumed car/truck fleet mix and resulting fleet average CO_2 g/mile emissions targets for each of these analyses. Table 1-5 provides per vehicle costs in 2025 broken down separately for cars and trucks in the light-duty vehicle fleet. The CEMMS analysis in RIA Chapter 4.1.3 found fleet-level per vehicle costs of $759 and $1000 for MY 2025 and MY 2026, respectively, and previous EPA analyses ranged from $922 to $1228 per vehicle for a roughly comparable level of stringency.[c]

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[b] The CCEMS analysis for this rule described in Chapter 4 uses AEO2021 for estimating gasoline prices. In general, AEO2021 reference, high, and low estimates for the retail price of gasoline are lower than comparable cases within AEO2016 and AEO 2017. For example, in 2025 the AEO2021 reference retail gasoline price in 2018$ is estimated to be $2.44 per gallon vs. $3.13 and $3.05 per gallon for AEO2016 and AEO2017, respectively.

[c] Please note, however, that there are differences in the "no action" cases used for determining costs between the final standards and the previous 2012 - 2018 EPA analyses. For a complete description of the "no action" case used for this rulemaking, please see Chapter 4.

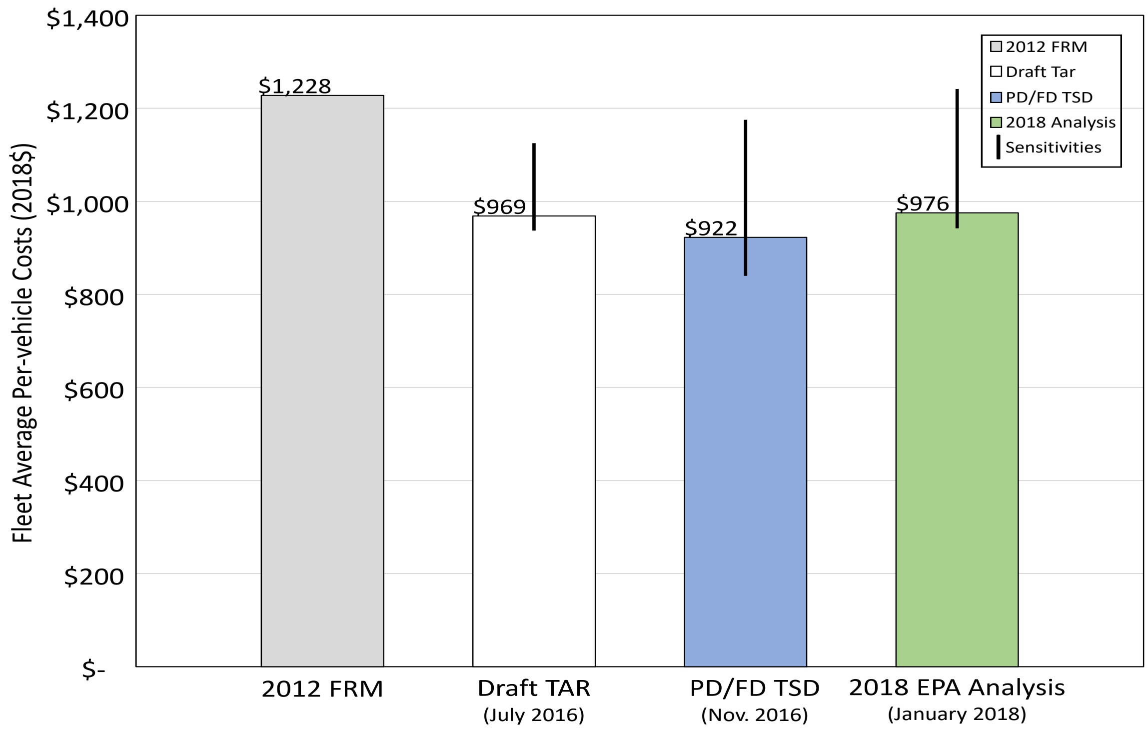

Figure 1-4: Comparison of fleet average (car and truck), per-vehicle technology costs in 2025 from the 2012 FRM to subsequent analyses conducted by EPA during the MTE (2018$). Vertical lines on top of the bars represent the range of sensitivity analyses conducted.

Table 1-3: Comparison of technology penetrations into the light-duty fleet and per vehicle costs in 2025 (incremental to 2021) for the 2012 FRM compared to analyses conducted by EPA under the MTE. All per vehicle costs are shown in 2018$ to maintain consistency with other analyses within this RIA

Technology [1]	2012 Final Rule [2]	Draft TAR [3]				PD/FD TSD [4]				Updated EPA 2018 Analysis [5],[6],[7]			
		Primary Analysis	Range of Sensitivities Analyzed			Primary Analysis	Range of Sensitivities Analyzed			Primary Analysis	Range of Sensitivities Analyzed		
Advanced High-efficiency Engines [8]	93%	81%	58%	to	86%	62%	36%	to	82%	67%	56%	to	73%
Cylinder Deactivation	not modeled	not modeled	not modeled			49%	43%	to	55%	28%	24%	to	31%
8 speed and other advanced transmissions (%) [9]	91%	90%	89%	to	91%	93%	92%	to	94%	90%	90%	to	94%
Mass reduction (%) [10]	-7%	6%	2%	to	6%	8%	1%	to	9%	4%	2%	to	5%
Off-cycle technology (%)	not modeled	not modeled	not modeled			26%	8%	to	53%	not modeled	not modeled		
Stop-start (%)	15%	20%	15%	to	31%	15%	12%	to	39%	16%	12%	to	20%
Mild Hybrid (%)	26%	18%	13%	to	38%	18%	16%	to	27%	1%	0%	to	3%
Strong Hybrid (%)	5%	2.6%	2.0%	to	3.0%	2%	2%	to	3%	2%	1%	to	2%
PHEV (%) [11]	0%	1.7%	2%	to	2%	2%	2%	to	2%	1%	1%	to	1%
BEV (%) [11]	2%	2.6%	2.0%	to	3.0%	3%	2%	to	4%	2%	1%	to	2%
Per vehicle cost (2018$)	$1,228	$969	$938	to	$1,125	$922	$840	to	$ 1,175	$976	$942	to	$1,242

Notes:
[1] Technology penetrations shown are absolute and MY 2025 vehicle costs are incremental to MY 2021.
[2] The 2012 FRM values are based on the AEO2012 Early Release "Reference Case" and analytical results were originally reported as average per vehicle costs of $1070 in 2010$.
[3] The Draft TAR values are based on the AEO 2015 "Reference Case" and analytical results were originally reported as average per vehicle costs of $894 in 2013$.
[4] The Proposed/Final Determination values are based on the AEO 2016 "Reference Case", which included a 53 percent/47 percent car/truck mix. Analytical results were originally reported as average per vehicle costs of $875 in 2015$.
[5] The 2018 Updated Analysis values are based on the AEO 2017 "Reference Case", which included a 42 percent/58 percent car/truck mix. Analytical results were originally reported as average per vehicle costs of $935 in 2016$.
[6] Advanced high-efficiency engines updated based on benchmarking of MY 2016 and MY 2017 OE engines.
[7] Lumped parameter modeling was completely removed in favor of peer reviewed response surface equations based entirely on ALPHA vehicle modeling.
[8] Includes both turbocharged/downsized and Atkinson Cycle engines.
[9] Including continuously variable transmissions (CVT).
[10] The mass reductions are fleet average percent reduction in curb weight relative to the 'null' package.
[11] BEV and PHEV penetrations include the California Zero Emission Vehicles (ZEV) program.

As EPA analyses were updated for the MTE through 2018, projected 2025 fuel prices decreased, the car/truck fleet mix shifted to a higher percentage of trucks, and the fleet CO_2 g/mile targets increased relative to the analysis for the 2012 FRM (Table 1-4).

The MTE analyses reflect an approximate $200 decrease in per vehicle fleet costs relative to the 2012 FRM analysis. Some of the MTE sensitivity analyses have per vehicle costs that are approaching or approximately equivalent to that of the 2012 FRM analysis. Despite considerable updates to the EPA analyses between 2012 and 2018, and a significant increase in the percentage of trucks in light-duty fleet (from 33 percent in the 2012 FRM analysis to 58 percent in the 2018 analysis), per vehicle costs for either the light-duty vehicle fleet (Figure 1-4) or separately for light-duty car or trucks (Table 1-5) have remained remarkably stable.

Table 1-4: Comparison of fuel price, percentage of cars and trucks in the fleet, and CO_2 fleet average emissions targets when taking into consideration the car and truck fleet mix for the 2012 FRM compared to analyses conducted by EPA under the MTE.

	2012 Final Rule [1]	Draft TAR [2]	PD/FD TSD [3]	Updated EPA 2018 Analysis [4]
2025 Fuel Price	$4.44	$3.20	$3.13	$3.05
2025 Car/Truck Fleet Mix[5]	67%/33%	52%/48%	53%/47%	42%/58%
2025 Fleet CO_2 Target (g CO_2/mi)	163	175	173	180

Notes:
[1] AEO 2011 Reference Case, fuel price converted to 2018$
[2] AEO 2015 Reference Case, fuel price converted to 2018$
[3] AEO 2016 Reference Case, fuel price converted to 2018$
[4] AEO 2017 Reference Case, fuel price converted to 2018$
[5] Car/Truck definitions used by EPA for GHG standards differ from those used by AEO. The Car/Truck Fleet Mix in 2025 is based upon EPA's regulatory car and truck definitions.

Table 1-5: Comparison per vehicles costs for passenger cars, light-duty trucks and the combined light-duty vehicle fleet in 2025 (incremental to 2021) for the 2012 FRM compared to analyses conducted by EPA under the MTE. Per vehicle costs are shown in 2018$ to maintain consistency with other analyses within this RIA.

	2012 Final Rule [1]	Draft TAR [2]	PD/FD TSD [3]	Updated EPA 2018 Analysis [4] (sensitivity range in parentheses)
Car	$1,101	$766	$790	$805
				($805 - $1,021)
Truck	$1,487	$1,191	$1,073	$1,098
				($1,010 - $1,454)
Fleet	$1,228	$969	$922	$976
				($942 - $1,242)

Notes:
[1] AEO 2011 Reference Case, converted to 2018$
[2] AEO 2015 Reference Case, converted to 2018$
[3] AEO 2016 Reference Case, converted to 2018$
[4] AEO 2017 Reference Case, converted to 2018$

1.3 Agency Actions, March 2017 - April 2020

1.3.1 2017 Reconsideration of the MTE Final Determination and 2018 MTE Final Determination

On March 15, 2017 EPA announced that the final determination, issued on January 12, 2017, would be reconsidered in coordination with NHTSA. On April 2, 2018, a new Mid-term Evaluation Final Determination was signed, which withdrew the previous Final Determination and found that the model year 2022-2025 greenhouse gas standards were not appropriate and should be revised.[25]

1.3.2 SAFE

In April 2020, EPA published "The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks," a final rule amending the 2012 FRM beginning with MY 2021 by establishing new and substantially less stringent GHG standards for MY 2021 and later light-duty vehicles.[26]

On January 20, 2021, President Biden signed Executive Order 13990, which issued the following directives to EPA and other federal agencies:

"Section 1. Policy. Our Nation has an abiding commitment to empower our workers and communities; promote and protect our public health and the environment; and conserve our national treasures and monuments, places that secure our national memory. Where the Federal Government has failed to meet that commitment in the past, it must advance environmental justice. In carrying out this charge, the Federal Government must be guided by the best science and be protected by processes that ensure the integrity of Federal decision-making. It is, therefore, the policy of my Administration to listen to the science; to improve public health and protect our environment; to ensure access to clean air and water; to limit exposure to dangerous chemicals and pesticides; to hold polluters accountable, including those who disproportionately harm communities of color and low-income communities; to reduce greenhouse gas emissions; to bolster resilience to the impacts of climate change; to restore and expand our national treasures and monuments; and to prioritize both environmental justice and the creation of the well-paying union jobs necessary to deliver on these goals.

To that end, this order directs all executive departments and agencies (agencies) to immediately review and, as appropriate and consistent with applicable law, take action to address the promulgation of Federal regulations and other actions during the last 4 years that conflict with these important national objectives, and to immediately commence work to confront the climate crisis.

Sec. 2. Immediate Review of Agency Actions Taken Between January 20, 2017, and January 20, 2021. (a) The heads of all agencies shall immediately review all existing regulations, orders, guidance documents, policies, and any other similar agency actions (agency actions) promulgated, issued, or adopted between January 20, 2017, and January 20, 2021, that are or may be inconsistent with, or present obstacles to, the policy set forth in section 1 of this order. For any such actions identified by the agencies, the heads of agencies shall, as appropriate and consistent with applicable law, consider suspending, revising, or rescinding the agency actions. In addition, for the agency actions in the 4 categories set forth in subsections (i) through (iv) of this section, the head of the relevant agency, as appropriate and consistent with applicable law, *shall consider publishing for notice and comment a proposed rule suspending, revising, or rescinding the agency action within the time frame specified.*

…(ii) Establishing Ambitious, Job-Creating Fuel Economy Standards: 'The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Part One: One National Program,' 84 FR 51310 (September 27, 2019), by April 2021; and 'The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks,' 85 FR 24174 (April 30,2020), by July 2021. In considering whether to propose suspending, revising, or rescinding the latter rule, the agency should consider the views of representatives from labor unions, States, and industry."[27]

With respect to § 2(ii) of Executive Order 13990 for the purposes of this document, we are referring to 84 FR 51310 as "SAFE" and 85 FR 24174 as "SAFE2". The revision of MY 2023 to MY 2026 Light-duty Vehicle GHG standards under SAFE2 is the purpose of the Notice of Proposed Rulemaking of which this Regulatory Impact Analysis is a part. Reconsideration of SAFE is the subject of a separate Agency action.[28]

In response to this Executive Order, EPA has considered taking action under the Clean Air Act with respect to the SAFE GHG emissions standards. As described in further detail in Preamble Section VI and elsewhere in the preamble to this rulemaking, we are finalizing more stringent GHG standards under our Clean Air Act authority. For more information regarding the SAFE rule and why EPA believes that the revised final standards are appropriate, see section I.A.1 of the preamble to this final rule.

1.3.2.1 New GHG Compliance Flexibilities Established Under SAFE2

As part of the amendment of MY 2021 and later GHG emissions standards under SAFE2, a small number of flexibilities related to real world fuel efficiency improvements were included. EPA continued to allow manufacturers to make improvements related to air conditioning refrigerants and leakage and credit those improvements toward compliance with GHG standards. EPA made no changes to the 10 g-CO_2/mi off-cycle credit cap. EPA also extended the ‘‘0 g/mi upstream’’ incentive for electric vehicles through 2026 beyond its original sunset of MY 2021 and established a new credit multiplier for natural gas vehicles through the 2026 model year. For natural gas vehicles, both dedicated and dual-fueled, EPA established a multiplier of 2.0 for model years 2022–2026.

To support easier use of certain real world fuel efficiency improvements, EPA added high efficiency alternators and advanced A/C compressors to the off-cycle credit menu to help streamline the program by allowing manufacturers to select the menu credit g/mi values rather than continuing to seek credits through the public approval process. The credit levels added to the menu were based on data previously submitted by multiple manufacturers through the off-cycle credits application process. The high efficiency alternator credit is scalable with efficiency, providing an increasing credit value of 0.16 grams/mile CO_2 per percent improvement as the efficiency of the alternator increases above a baseline level of 67 percent efficiency. The advanced A/C compressor credit value is 1.1 grams/mile for both cars and light trucks. For more information on any aspect of these changes see 84 FR 24174, April 30, 2020.[26] For a summary of the final revisions of the averaging banking and trading program and credit carry forward provisions, please refer to Section II.A. 4. within the Preamble for the Final Rule.

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Chapter 2: Technology Feasibility, Effectiveness, Costs, and Lead-time

EPA is finalizing revised national greenhouse gas (GHG) emissions standards for passenger cars and light trucks under section 202(a) of the Clean Air Act (CAA). Section 202(a) requires EPA to establish standards for emissions of air pollutants from new motor vehicles which, in the Administrator's judgment, cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. The transport sector is currently the largest source of anthropogenic GHG emissions in the U.S. There are technologically feasible to achieve additional reductions for MY 2023 through MY 2026 light-duty vehicles at reasonable cost per vehicle and without compromise to vehicle utility or safety. As in many prior EPA mobile source rulemakings, the decision on what standards to set and on what implementation timeframe is largely based on the availability, capability, and cost of the emissions control technology along with the need for reductions of GHG and the benefits of doing so. This final rule will also establish a path toward more significant reductions in the years following 2026.

2.1 Final Standards

As with the existing GHG standards, EPA is finalizing separate car and truck standards—that is, vehicles defined as cars have one set of footprint-based curves, and vehicles defined as trucks have a different set.[1] Generally, passenger cars include cars and smaller cross-overs and SUVs, while the truck category includes larger cross-overs and SUVs, minivans, and pickup trucks. Because compliance is based on a sales-weighting of the full range of vehicles in a manufacturer's car and truck fleets, the footprint based CO_2 emission levels of specific vehicles within the fleet are referred to as targets, rather than standards. In general, for a given footprint, the CO_2 g/mile target for trucks is higher than the target for a car with the same footprint. The curves are defined mathematically in EPA's regulations by a family of piecewise linear functions (with respect to vehicle footprint) that gradually and continually ramp down from the MY 2022 curves established in the SAFE rule. EPA's minimum and maximum footprint targets and the corresponding cutpoints are provided below in Table 2-1 for MYs 2023-2026 along with the slope and intercept defining the linear function for footprints falling between the minimum and maximum footprint values. For footprints falling between the minimum and maximum, the targets are calculated as follows: Slope x Footprint + Intercept = Target. Figure 2-1 and Figure 2-2 provide the existing MY 2021-2022 and final MY 2023-2026 footprint curves graphically for both cars and light trucks, respectively.

Table 2-1: Final Footprint-based CO_2 Standard Curve Coefficients

	Car				Truck			
	2023	2024	2025	2026	2023	2024	2025	2026
MIN CO_2 (g/mi)	145.6	138.6	130.5	114.3	181.1	172.1	159.3	141.8
MAX CO_2 (g/mi)	199.1	189.5	179.4	160.9	312.1	296.5	277.4	254.4
Slope (g/mi/ft2)	3.56	3.39	3.26	3.11	3.97	3.77	3.58	3.41
Intercept (g/mi)	-0.4	-0.4	-3.2	-13.1	18.4	17.4	12.5	1.9
MIN footprint (ft2)	41	41	41	41	41	41	41	41
MAX footprint (ft2)	56	56	56	56	74	74	74	74

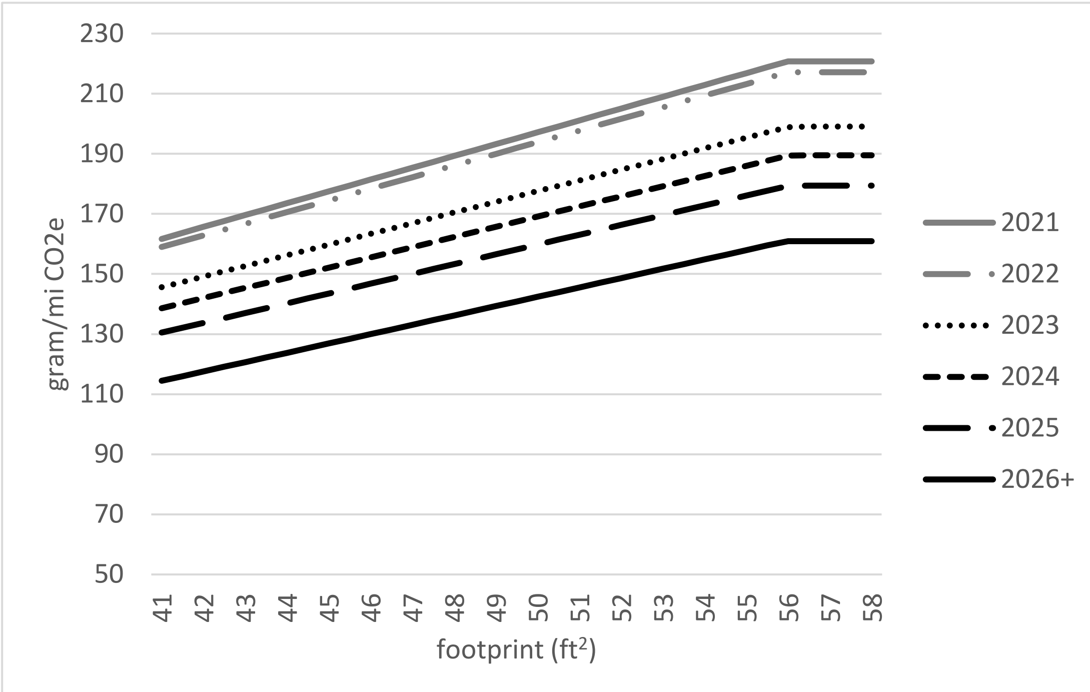

Figure 2-1: CO_2 vs Footprint Compliance Curves for Cars

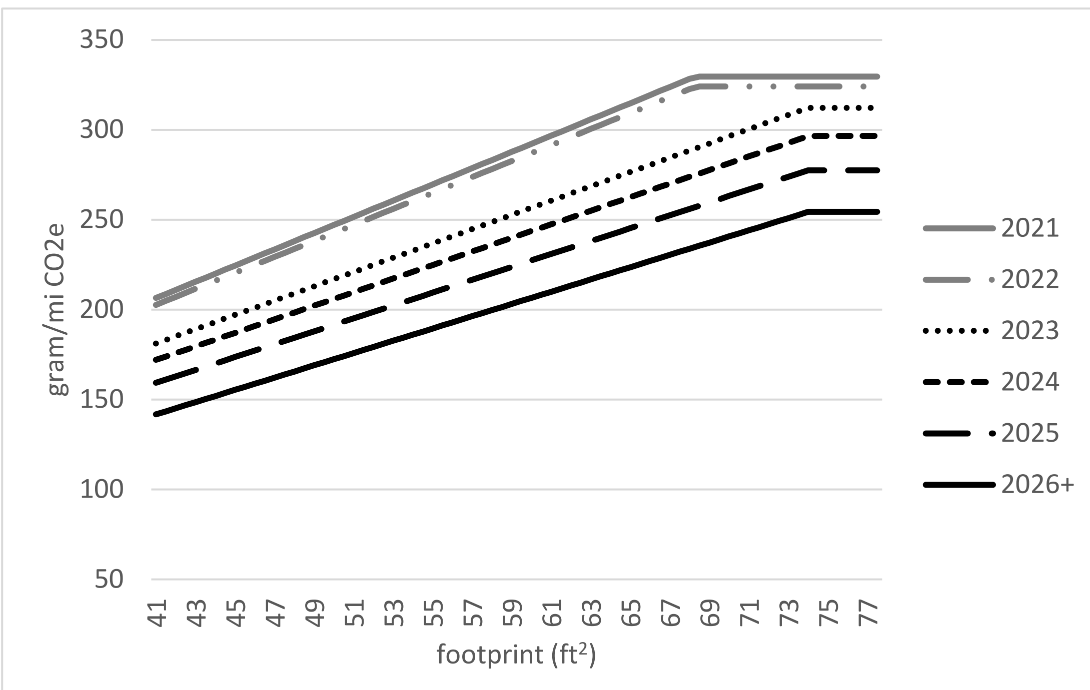

Figure 2-2: CO_2 vs Footprint Compliance Curves for Trucks

The shapes of the MY 2023-2026 car curves are similar to the MY 2022 curve. By contrast, the MY 2023-2026 truck curves return to the cutpoint of 74.0 sq ft originally established in the 2012 rule but changed in the SAFE rule.[2] The gap between the 2022 curves and the 2023 curves is indicative of the design of the final standards as described earlier, where the gap between the

MY 2022 and MY 2023 curves is roughly double the gap between the curves for MYs 2024-2026.

Figure 2-3 shows EPA's final standards, expressed as year-over-year fleetwide GHG emissions targets (cars and trucks combined), projected through model year 2026 and beyond. For comparison, the figure also shows the corresponding targets for the recent SAFE FRM and the 2012 FRM. The final fleet targets start from the prior SAFE FRM targets for model year 2022, but ramp down considerably in model year 2023, nearly reaching the 2012 FRM targets for that model year. The final fleet targets approximately parallel the downward slope of the 2012 FRM targets for model years 2023 and 2024, are approximately equivalent to the 2012 FRM in 2025 (the last year of the 2012 FRM), and then decrease at a more stringent downward slope for one additional model year to model year 2026 (the last year of the SAFE FRM). As with all EPA light-duty GHG rules, the standards would then remain in place at the same level for all subsequent model years unless revised by a subsequent rulemaking. Table 2-2 presents EPA's final standards presented in Figure 2-3, again in terms of the projected overall fleetwide CO_2-equivalent emission compliance target levels.

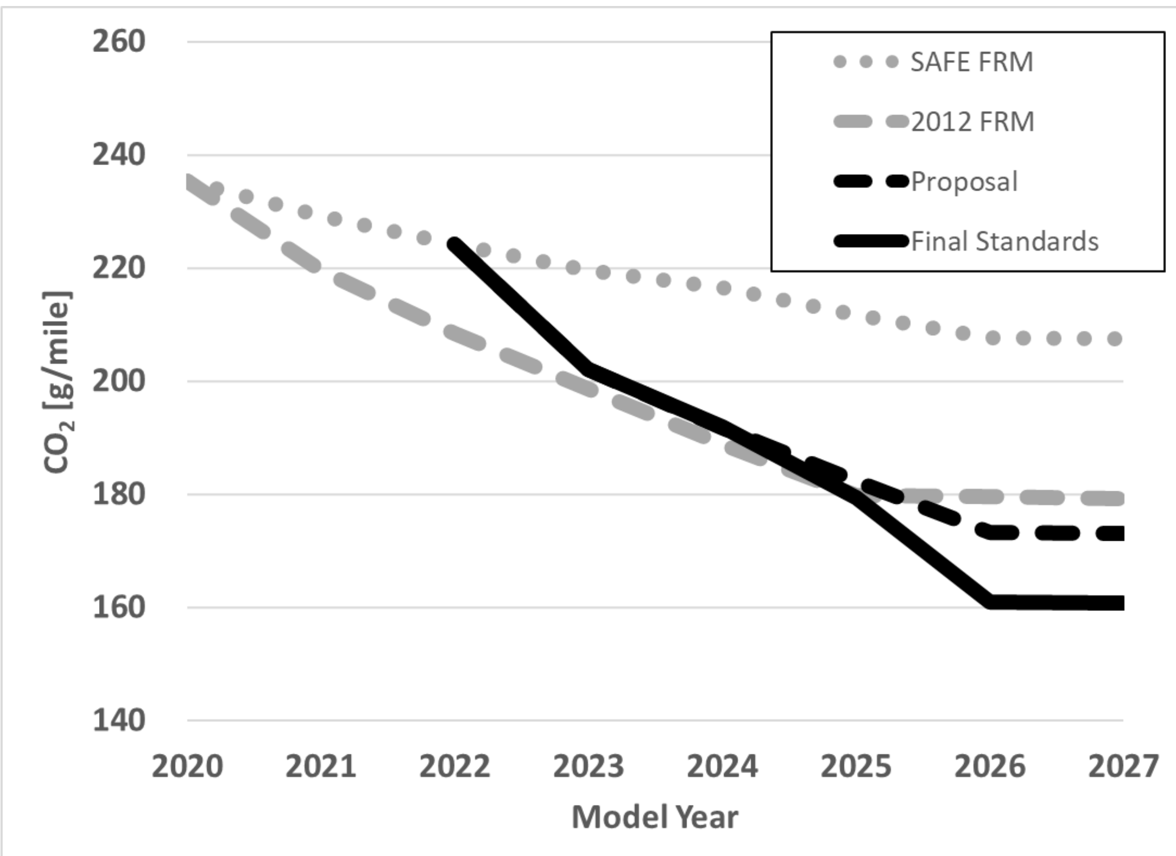

Figure 2-3: Final Fleet-Wide CO_2-Equivalent g/mi Compliance Targets (solid black line), Compared to 2012 FRM, SAFE Rule, and Proposal.

Table 2-2: Estimated Fleet-wide CO_2 Target Levels Corresponding to the Final Standards

Model Year	Cars CO_2 (g/mile)	Trucks CO_2 (g/mile)	Fleet CO_2 (g/mile)
2023	166	233	202
2024	158	222	192
2025	149	207	179
2026 and later	132	187	161

2.1.1 Revised Final Compliance Incentives and Flexibilities

EPA is finalizing provisions for credit extension that are more targeted than those proposed. EPA proposed to extend credit carry-forward for MY 2016-2020 credits to allow more flexibility for manufacturers in using banked credits in MYs 2023-2026. Specifically, EPA proposed a two-year extension of MY 2016 credits and a one-year extension of MY 2017-2020 credits. After considering comments and further analyzing the need for extended credit life, EPA is adopting a narrower approach for the final rule of only adopting a one-year credit life extension for MY 2017-2018 credits so they may be used in MYs 2023-2024, respectively. For details regarding the averaging banking and trading program and credit carry forward provisions, please refer to section II.A.4 within the Preamble for the Final Rule.

2.2 Light-duty Vehicle Technology Feasibility

2.2.1 Feasibility of the Revised Final Standards

Based upon the light-duty vehicle fleet compliance analysis summarized within Chapter 4 of this RIA and the updated analytical results for the final rule in RIA Chapters 5, 6, and 10; and consistent with the extensive public record established by EPA with its publication of the 2012 FRM, July 2016 Draft TAR, November 2016 Proposed Determination January 2017 Final Determination, August 2021 NPRM; and taking into consideration the averaging, banking, and trading provisions; the final MY 2023 and later light-duty GHG standards are feasible using existing vehicle technologies that are already widely available within the current light-duty vehicle fleet.

The feasibility of the revised standards is best understood within the context of the decade-long light-duty vehicle GHG emissions reduction program in which the automotive industry has innovated a wide range of GHG-reducing technologies. Over this time, the industry has had the ability to plan for increasingly stringent GHG emissions requirements. The result has been the widespread and continual introduction of new and improved GHG-reducing technologies across the industry, many of which were in the early stages of development at the beginning of the program in 2012. See Chapter 2.3 for a discussion of technological progression, status of technology penetration, and Chapter 4.1.4 for our assessment of the continuing technology penetration across the fleet.

The technological achievements already developed and increasing in application to vehicles within the current new vehicle fleet (Chapter 2.3) will enable the industry to achieve the final standards even without the development and implementation of additional technologies. Compliance with the final standards, adjustment to the pace of technology penetration of existing GHG reduction technologies, and adjustment to the management of both existing GHG credits and particularly the generation of credits under the revised light-duty GHG program will occur within the full context of the revised incentives and flexibilities that will be available under the Final Rule. As we discuss in Chapter 2.4, our assessment shows that a large portion of the current fleet (MY 2021 vehicles), across a wide range of vehicle segments, already meets future standards and that there are clear opportunities for automakers to focus their sales and marketing on these more efficient products.

The multi-year nature of automotive design and engineering development also means that the industry's product plans that were developed in response to the EPA's GHG standards finalized in 2012 for MYs 2017-2025 has largely continued despite the relaxation of GHG standards under SAFE that were promulgated in April 2020 with implementation beginning in MY 2021. This can also be seen within the increased penetration of GHG reducing technologies (Chapter 2.3). In previous comments on EPA's light-duty GHG and other light-duty vehicle programs, automakers have broadly stated that they require approximately five years to design, develop, and produce a new vehicle model. Thus, in most cases, vehicles that automakers intend to sell during the first years of these revised MY 2023 and later GHG standards were already designed under the original, and more stringent, GHG standards finalized in 2012 for those model years. At the time of the proposed rule, the relaxed GHG standards under the SAFE rule had been in place for little more than one year. During this time, the ability of the industry to commit to a change of plans to take advantage of the SAFE rule's relaxed standards, especially for MYs 2023 and later, was highly uncertain in light of pending litigation, and the automobile industry regularly expressed concern over the uncertain future of the SAFE standards. In fact, due in part to this uncertainty, five automakers voluntarily agreed to more stringent national emission reduction targets under the California Framework Agreements.[3] Therefore, based on the automakers' own past comments regarding product plan development and the regulatory and litigation history of the GHG standards since 2012, we believe that automakers continue to be largely on track in terms of technological readiness within their product plans to meet the approximate trajectory of increasingly stringent light-duty vehicle GHG standards initially promulgated in 2012.

Although we do not believe that automakers have significantly changed their product plans in response to the SAFE final rule issued in 2020, any that may have would have done so relatively recently and we would anticipate that their earlier product plans could be reinstated or adapted with minimal change. It is important to note that we have considered the need for manufacturers to transition from the SAFE standards (or the California Framework Agreement) to standards that are similar in stringency to the 2012 standards and have structured the revised standards to be less stringent than the 2012 standards for model years 2023 and 2024, and of comparable stringency for model year 2025. EPA considers this an important aspect of its analysis because it mitigates concerns about lead-time for manufacturers to meet the revised standards beginning with the 2023 model year. We see no reason to expect that the major GHG-reducing technologies that automakers already developed, increasingly introduced (see Chapter 2.3), or already planned for near-term implementation, will not be available for MY 2023 and later vehicles. Thus, in contrast to the situation that existed prior to EPA's adoption of the initial light-duty GHG standards in the 2012 rule, automakers now have had the benefit of at least 8-9 years of planning and development for increasing levels of GHG-reducing technologies in preparation for meeting these revised standards.

Further support that the technologies needed to meet the standards do not need to be developed and are already widely available and in use on vehicles can be found in the fact that five vehicle manufacturers, representing nearly 30 percent of U.S. auto sales, agreed in 2019 with the State of California that their nationwide fleets would meet GHG emission reduction targets more stringent than the applicable EPA standards for MYs 2021 and 2022, and similar to the final EPA standards for MYs 2022 and 2023.[3] These voluntary actions by automakers speak directly to the feasibility of meeting standards at least as stringent as those under the California Framework. Thus, the California Framework voluntary targets were another consideration in our development and assessment of the Final EPA light-duty vehicle GHG standards.

It is important to note that our conclusion that the revised program is technologically feasible is based in part on a projection that the standards will be met largely with the kinds of advanced light-duty vehicle engine technologies, transmission technologies, electric drive systems, aerodynamics, tires, and vehicle mass reduction already in place in vehicles within today’s fleet.

Our updated analysis projects that the final standards can be met with a fleet that achieves a gradually increasing market share of EVs and PHEVs, approximately 7 percent in MY 2023 up to about 17 percent in MY 2026 (see Chapter 4 and also Section III.C within the Preamble to this Final Rule). While this represents an increasing penetration of zero-emission and near-zero emission vehicles into the fleet during the 2023-2026 model years, we believe that the growth in the projected rate of penetration is consistent with current trends and market forces. We believe that the continuation of trends already underway, as exemplified in part by manufacturers’ public announcements about their plans to transition to electrified vehicles, as well as continuing advancements in EV technology, support the feasibility of this level of EV and PHEV penetration during the time period of the rule. Moreover, EPA is committed to encouraging the rapid deployment of zero-emission vehicles, and we are finalizing compliance flexibilities and incentives to support this transition (see Sections I.B.2 and II.B within the Preamble to this Final Rule).

2.2.2 Alternatives to the Revised Standards

In addition to the revised standards, we analyzed both a more stringent and a less stringent alternative. The less stringent alternative in this FRM is equivalent to the Proposal Standards and uses the corresponding footprint-based car and truck standards curves (i.e, the curve coefficients) from the NPRM. The Proposed Standards were supported in public comments by traditional internal combustion engine equipped vehicle manufacturers. The Proposal as analyzed also included incentive multipliers consistent with those in EPA's NPRM.

The more stringent alternative (Alternative 2 minus 10) used the coefficients from the more stringent alternative (Alternative 2) in the NPRM with the additional increase in stringency of 10 g/mile in MY 2026. Alternative 2 minus 10 differs from the final standards only in MY 2023 and 2024. Because we wanted maximum stringency for this alternative, we did not include the final rule's advanced technology multipliers and cumulative credit cap associated with those multipliers for MYs 2022 and later.

The fleet average targets for the two scenarios compared to the revised standards are provided in Table 2-3 below. As described in 2.3.3 and elsewhere, the potential for increased penetration of ZEVs was considered as a factor in the feasibility of the final standards and Alternative 2 minus 10 standards.

Table 2-3: Projected Fleet Average Target Levels for Revised Standards and Alternatives (CO_2 grams/mile)*

Model Year	Final Projected Targets	Proposal Projected Targets	Alternative 2 minus 10 Projected Targets
2021**	229	229	229
2022**	224	224	224
2023	202	202	198
2024	192	192	186
2025	179	182	180
2026	161	173	161

* Targets shown are modeled results and, therefore, reflect fleet projections impacted by the underlying standards. For that reason, slight differences in targets may occur despite equality of standards in a given year.
** SAFE rule targets included here for reference.

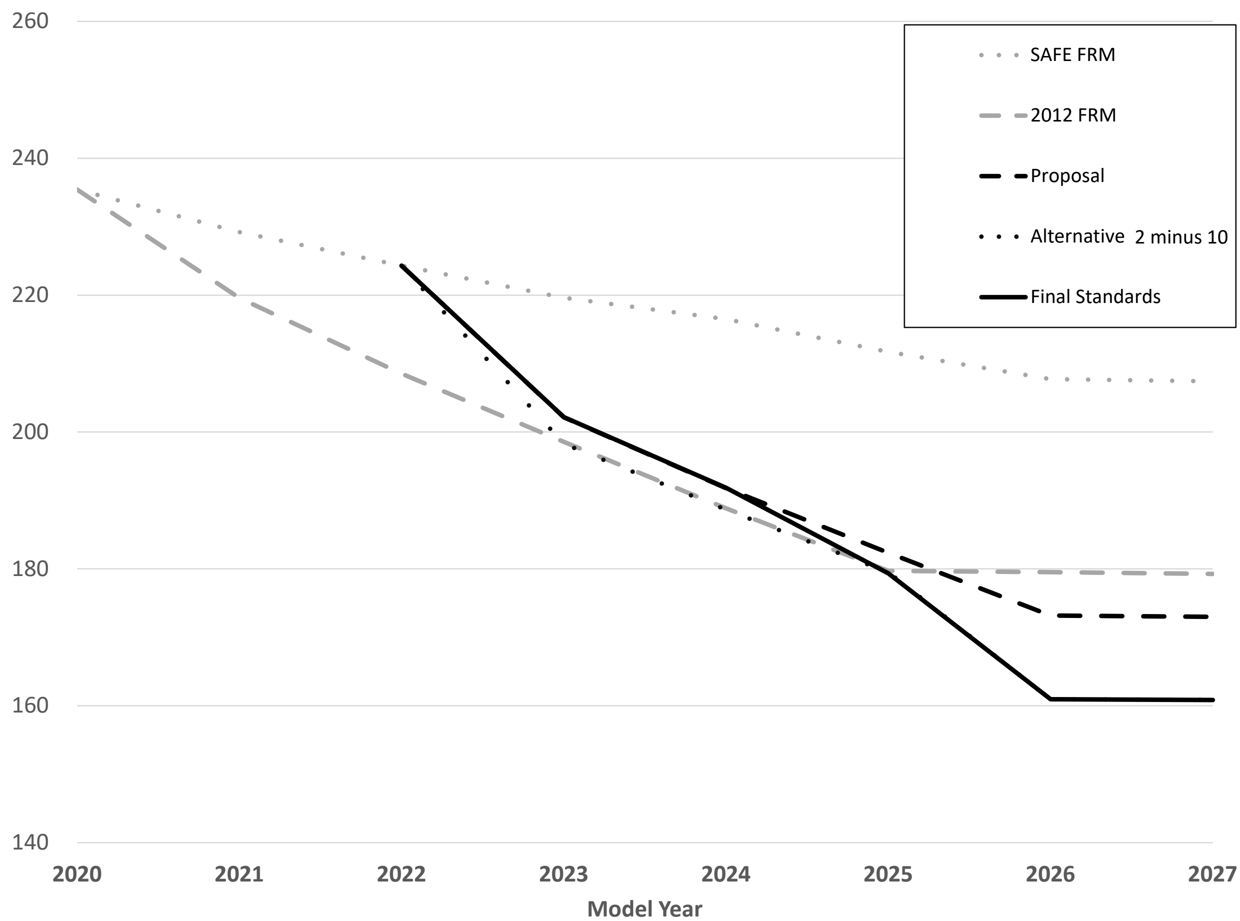

Figure 2-4: Final Rule Fleet Average Targets Compared to the Proposal and Alternative 2 minus 10

As shown in Figure 2-4, the range of analyzed scenarios that we considered was fairly narrow, with the revised final standard targets differing from the Proposal and Alternative 2 minus 10 targets in any given model year in 2023-2026 by 2 to 12 g/mile. We believe that this approach is reasonable and appropriate considering the relatively short lead time for the revised standards, our assessment of feasibility, the existing automaker commitments to meet the California Framework (representing about 28 percent of the auto market), the standards adopted in the 2012 rule, and the need to reduce GHG emissions. The analysis of costs and benefits of the Final Standards, the Proposal and Alternative 2 minus 10 are summarized within Chapters 4, 5, 6, and 10.

The revised final standards, the Proposal, and the Alternative 2 minus 10 all incorporate year-over-year increases in GHG stringency, with varying starting stringencies in MY 2023, varying ending stringencies in MY 2026, and fairly linear increases in stringency between MY 2023 and 2025 that would essentially follow the same slope as the 2012 program. All three potential programs would also, by MY 2026, result in standards at least as stringent or more stringent when compared to the last year (MY 2025) of the 2012 program.

For the Proposal, the standards would have slightly less stringency than the 2012 rule for model years 2023-2025 and higher stringency in model year 2026, resulting in a less stringent program compared to the 2012 rule until MY 2026. Chapter 5.1.1.2 shows the associated lower amount of GHG reductions achieved under the Proposal when compared to the final standards.

For Alternative 2 minus 10, the standards for model years 2023 through 2025 would match the stringency level of the standards in the 2012 rule and would continue to increase in stringency for one additional year in MY 2026. Consistent with EPA's previous discussions regarding feasibility, compliance costs, and lead time, we believe that Alternative 2 minus 10 are also technologically feasible.

2.3 Vehicle Technologies

For a summary of the effectiveness and cost of technologies used by EPA for modeling compliance with the final standards, see Chapter 4.1 of this RIA. A complete summary of vehicle technologies and associated GHG effectiveness for internal combustion engine technologies, transmission technologies, vehicle electrification, aerodynamics, tires, and vehicle mass reduction can be found within Chapter 2.2 of the Technical Support Document (TSD) for the November 2016 Proposed Determination.[4] We still believe this document to be a sound and thorough examination of the available technologies and their GHG effectiveness for the timeframe of this rulemaking. In fact, some vehicle manufacturers have recently made public statements regarding their plans to discontinue the development of conventional, internal combustion engine-based technologies to focus on the electrified vehicle technologies.[5] In their press release announcing their goal to be carbon neutral in 2040, GM stated that "The company will also continue to increase fuel efficiency of its traditional internal combustion vehicles in accordance with regional fuel economy and greenhouse gas regulations. Some of these initiatives include fuel economy improvement technologies, such as Stop/Start, aerodynamic efficiency enhancements, downsized boosted engines, more efficient transmissions and other vehicle improvements, including mass reduction and lower rolling resistance tires."[6] Although some manufacturers have indicated a reduced focus on internal combustion engine (ICE) technologies, EPA has continued its independent evaluation of advanced engine and transmission technologies and has updated and improved our assessment of light-duty vehicle GHG emissions over the intervening years since publication of the TSD.[7] The results of these analyses have been published in over a dozen peer-reviewed technical and journal papers.[8,9,10,11,12,13,14,15,16,17,18,19,20,21,22]

The percentage share of specific MY 2015 to MY 2020 engine and transmission technologies are summarized from EPA Automotive Trends Report data in Table 2-4 and Table 2-5 respectively.[23] In MY 2020, hybrid electric vehicles (HEV) accounted for approximately 6.5 percent of vehicle sales, while plug-in electric hybrids (PHEV) and battery electric vehicles (BEV) together comprised 4 percent of sales. Thus, powertrain electrification of all types has increased more than 3-fold from MY 2015 to MY 2020. The pace of introduction of new EV models is rapidly increasing. Nearly 100 pure electric EV models are expected to be introduced in the United States by the end of 2024.[24] The sales of vehicles with 12V start/stop systems have increased from approximately 7 percent to approximately 42 percent between MY 2015 and MY 2020.

As of MY 2020, more than half of light-duty gasoline spark ignition engines now use direct injection (GDI) and more than a third are turbocharged.[a,25] Nearly half of all light-duty vehicles have planetary automatic transmissions with 8 or more gear ratios, and a fourth are using continuously variable transmissions (CVT). We anticipate that these GHG reducing technologies will continue to increasingly penetrate the light-duty vehicle fleet for MYs 2023-2026.

Table 2-4: Production Share by Engine Technologies for MY 2015-2020

	Powertrain Technologies					Engine Technologies							
Model Year	Gasoline	Gasoline HEV	Diesel	PHEV	BEV	GDI	Port	Avg. Displ. (L)	HP	VVT	CD	Turbo	Stop/ Start
2015	95.9%	2.4%	0.9%	0.2%	0.5%	41.9%	56.7%	2.90	229	97.2%	10.5%	15.7%	7.1%
2016	96.9%	1.8%	0.5%	0.3%	0.5%	48.0%	51.0%	2.85	230	98.0%	10.4%	19.9%	9.6%
2017	96.1%	2.3%	0.3%	0.8%	0.6%	49.7%	49.4%	2.85	234	98.1%	11.9%	23.4%	17.8%
2018	95.1%	2.3%	0.4%	0.8%	1.4%	50.2%	48.0%	2.82	241	96.4%	12.5%	30.0%	29.8%
2019	94.4%	3.8%	0.1%	0.5%	1.2%	52.9%	45.7%	2.85	245	97.2%	14.9%	30.0%	36.9%
2020 (prelim)	88.5%	6.5%	1.0%	0.7%	3.3%	55.3%	40.3%	2.75	247	94.0%	13.8%	35.3%	42.2%
Note: Adapted from the 2020 EPA Automotive Trends Report.[23]													

Table 2-5: Production Share by Transmission Technologies for MYs 2015-2020

Model Year	Manual	Automatic with Lockup	Automatic without Lockup	CVT (Hybrid)	CVT (Non-Hybrid)	4 Gears Or Fewer	5 Gears	6 Gears	7 Gears	8+ Gears	Average No. of Gears
2015	2.6%	72.3%	1.4%	2.2%	21.5%	1.5%	4.5%	54.2%	3.1%	13.0%	5.9
2016	2.2%	72.3%	2.6%	1.7%	21.2%	1.1%	3.0%	54.9%	2.9%	15.3%	6.0
2017	2.1%	71.5%	2.6%	1.9%	21.8%	1.0%	2.4%	49.0%	3.4%	20.5%	6.1
2018	1.6%	72.8%	3.2%	1.7%	20.6%	1.9%	2.0%	37.6%	3.7%	32.5%	6.4
2019	1.4%	72.1%	2.4%	2.2%	21.9%	1.5%	1.6%	26.1%	2.6%	44.0%	6.6
2020 (prelim)	1.5%	66.1%	4.4%	3.1%	25.0%	3.4%	1.3%	15.8%	2.4%	49.0%	6.6
Note: Adapted from the 2020 EPA Automotive Trends Report.[23]											

[a] A technical assessment of the particulate matter (PM) emissions impacts of MY 2020-2021 light-duty vehicles using engines equipped with gasoline direct injection (GDI) and port fuel injection is included within a memo to the docket for this final rule.

2.3.1 Recent Advances in Internal Combustion Engines

The Automotive Trends Report does not separately track the introduction of HEV and non-HEV applications of Atkinson Cycle and Miller Cycle engines, however their application has been increasing over the past five years. Atkinson Cycle and Miller Cycle engines represent technologies that improve efficiency via use of increased expansion when compared to convention (Otto cycle) spark ignition engines. Although Atkinson and Miller Cycles are sometimes used interchangeably, EPA's use of the nomenclature refers specifically to either naturally-aspirated (Atkinson) or turbocharged (Miller) implementations. Recent implementations also include use of fast, wide-range of authority camshaft phasing to allow variation of effective compression ratio for load control and additional reduction of pumping losses. Most implementations over the last six years use gasoline direct injection (GDI) for additional knock mitigation.[b] For additional information on these technologies, see Chapter 2.2.1.2 "Descriptions of Technologies and Key Developments since the FRM" within the Technical Support Document for the November 2016 Proposed Determination (2016 TSD).[26]

Atkinson Cycle engines have been common in HEV applications for more than two decades. More recently, Toyota, Mazda, and Hyundai/Kia have been expanding the use of these engines in non-HEV applications to reduce fuel consumption and comply with GHG emissions standards. Since the publication of the 2016 TSD, there has also been a broader range of product introductions with Atkinson Cycle engines combined with gasoline direct injection (GDI) and either cylinder deactivation or cooled EGR. Mazda introduced fixed cylinder deactivation[c] on the base 2.5L Atkinsons Cycle engine in the MY 2018 CX-5 CUV and Mazda 6 passenger car. It was also introduced in the MY 2019 Mazda 3. Based on comparisons of certification data for comparable chassis and trim levels, Mazda's implementation of fixed cylinder deactivation provides an incremental effectiveness of approximately 2 percent beyond that of a 4-cylinder Atkinson Cycle engine without fixed cylinder deactivation.

Atkinson Cycle with cooled EGR has been applied to a broad range of both HEV and non-HEV passenger cars and crossover utility vehicles (CUV). Examples include the Toyota's "Dynamic Force" range of engines added as part of the Toyota New Global Architecture (TNGA).[27,28,29,30,31] Cooled EGR is used to reduce pumping losses and to mitigate combustion knock. These include the following Toyota engines: the M15A-FKS, M20A-FKS, and A25A-FKS non-HEV engines; and the M15A-FXE, M20A-FXS, and A25A-FXS HEV-specific engines used in the Toyota Corolla, Camry, Avalon, C-HR, RAV4, Highlander, Lexus ES and Lexus UX. In 2018, EPA conducted engine dynamometer benchmark testing of the Toyota 2.5L A25A-FKS engine with Atkinson Cycle and cooled EGR.[17] During testing on Federal Tier 2 certification fuel, the Toyota A25A-FKS engine demonstrated a peak brake thermal efficiency (BTE) of approximately 40 percent, the highest published BTE for a production, non-HEV engine. This represents a significant improvement over the peak BTE (typically 35-37 percent) of the naturally aspirated GDI engines that make up a majority of MY 2020 vehicle fleet. Atkinson Cycle engines were estimated to have GHG effectiveness of approximately 3.2 to 3.8 percent relative to over otherwise comparable naturally-aspirated GDI engines in non-HEV

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[b] Knock is an abnormal and potentially damaging form of combustion characterized by a very high rate of increase in cylinder pressure and high peak cylinder pressure.

[c] Fixed cylinder deactivation disables a fixed number of engine cylinders to reduce pumping losses at light load.

applications. EPA estimates that the addition of cooled EGR to an Atkinson Cycle engine further reduces 2-cycle GHG emissions by an additional 4.4 percent over Atkinson Cycle alone.

Both engine-dynamometer developmental work and benchmarking of production engines by EPA identified synergies between the use of fixed cylinder deactivation and cooled EGR on Atkinson Cycle engines when used in non-HEV applications.[32,33,34,17] Both EPA and other researchers have also identified synergies between the use of dynamic cylinder deactivation and cooled EGR on Atkinson Cycle engines. [17,35] EPA estimates that the addition of either fixed cylinder deactivation or dynamic cylinder deactivation[d] to an Atkinson Cycle engine with cooled EGR would provide an additional 2.3 percent or 7.9 percent reduction in 2-cycle GHG emissions, respectively.[17]

VW now offers EA888-3B 2.0L Miller Cycle engine as the base engine in the Passat and Arteon passenger cars and the Atlas and Tiguan CUVs. The MY 2022 Taos CUV will use the EA211 1.5L evo Miller Cycle engine as the base engine, which has a peak brake thermal efficiency of 38.1 percent.[36] A hybrid-specific version of this engine is under development by VW. When equipped with cooled-EGR and a variable-geometry turbo, it demonstrated a peak BTE of 41.5 percent.[36]

2.3.2 Changes to Engine Technologies Represented in the Analysis for the Final Rule

Analytical revisions to the modeling of light-duty vehicle compliance with the final standards and the resulting GHG emissions and vehicle technology costs are summarized within Chapter 4.1.

Within EPA's analysis, the different levels of HCR represent the following:

- HCR0: Atkinson Cycle with GDI and a geometric compression ratio of 13:1.
    - Examples: 2012 – 2016 Mazda vehicles with the SKYACTIV-G engine (which we benchmarked)
- HCR1: The addition of either cooled EGR or fixed cylinder deactivation (CDA) to HCR0.
    - Examples with cooled EGR: Many 2018 and nearly all 2019 and later Toyota vehicles with 4-cylinder engines (we benchmarked the Toyota Camry);
    - Examples with fixed CDA: 2017 and later Mazda vehicles with the SKYACTIVE-G engine
- HCR2: Atkinson Cycle with GDI, cooled EGR, and dynamic (individual cylinder) cylinder deactivation, and a geometric compression ratio of 13:1.[17]
    - For HEV applications, HCR2 represents the application of GDI, cooled EGR, higher compression and expansion ratio, and the use of a dedicated hybrid electric/engine powertrain strategy.[e]

[d] Dynamic cylinder deactivation is a newer, more capable system than fixed cylinder deactivation. Any number of cylinders can be deactivated or activated on a cycle resolved basis. The first production examples became available on GM full-frame trucks in MY 2019.

[e] Dedicated hybrid engines combine an engine and electric drive within a powertrain and calibrated in a synergistic manner that increases engine efficiency and avoids areas of engine operation prone to knock and/or low-speed preignition.

The restriction within the analysis of all HCR technologies to naturally aspirated engines with cylinder counts of 6 or less during compliance modeling was a means of restricting Atkinson Cycle from application to trucks and other applications having a specific need for additional torque reserve (e.g., trailer towing or high payload applications).

A change made in the analysis for the final rule relative to the proposal was to only include HCR2 as part of a sensitivity analysis for MY2025 and later vehicles. The individual technologies represented by HCR2 are all currently available within the current light-duty vehicle fleet, however the specific combination of technologies represented by HCR2 are not yet available in production light-duty vehicles. Thus, while we believe HCR2 to be technologically feasible, we made the decision to limit application of HCR2 to a sensitivity analysis applied to MY2025 and later as a conservative approach with respect to compliance with the light-duty GHG standards. Some manufacturers may choose to pursue a relatively low cost internal combustion engine technology like HCR2, however we believe that many manufactures will choose instead to instead focus near-term and future investment on powertrain electrification. Thus, we are showing 2 paths to compliance - a sensitivity analysis with an HCR2 compliance path and modeled compliance without HCR2. For more information on use of HCR2 within the analyses for the final rule, please refer to Chapters 4.1.1.3 and 4.1.5.1.

2.3.3 Vehicle Electrification

While we anticipate that the revised standards will be met primarily through the continued penetration of conventional powertrain (e.g., internal combustion engine, transmission) improvements and road-load reductions as outlined previously within the draft TAR,[37] the PD TSD,[38] and in the previous sections of this chapter, we anticipate that the design of a future, longer-term program beyond 2026 will further incorporate accelerating advances in zero-emission technologies.

A proliferation of recent announcements from automakers signals a rapidly growing shift in investment away from internal-combustion technologies and toward high levels of electrification. These automaker announcements are supported by continued advances in automotive electrification technologies, and further driven by the need to compete in a global market as other countries implement aggressive zero-emission transportation policies.

For example, in January 2021, General Motors announced plans to become carbon neutral by 2040, including an effort to shift its light-duty vehicles entirely to zero-emissions by 2035.[39] In March 2021, Volvo announced plans to make only electric cars by 2030,[40] and Volkswagen announced that it expects half of its U.S. vehicle sales will be all-electric by 2030.[41] In April 2021, Honda announced a full electrification plan to take effect by 2040, with 40 percent of its North American vehicle sales expected to be fully electric or fuel cell vehicles by 2030, 80 percent by 2035 and 100 percent by 2040.[42] In May 2021, Ford announced that they expect 40 percent of their global light-duty vehicle sales will be all-electric by 2030.[43] In June 2021, Fiat announced a move to all electric vehicles by 2030,[44] and in July 2021 its parent corporation Stellantis announced an intensified focus on electrification across all of its brands.[45] Also in July 2021, Mercedes-Benz announced that all of its new architectures would be electric-only from 2025, with plans to become ready to go all-electric by 2030 where possible.[46] In September 2021, Toyota announced large new investments in battery production and development to support an increasing focus on electrification.[47] On August 5, 2021, in conjunction with the announcement of Executive Order 14037, many of these automakers, as well as the United Auto

Workers and the Alliance for Automotive Innovation, expressed continued commitment to these announcements and support for the goal of achieving 40 to 50 percent sales of zero emissions vehicles by 2030.

These announcements, and others like them, continue a pattern over the past several years in which many manufacturers have taken steps to aggressively pursue zero-emission technologies, introduce a wide range of ZEV models, and reduce their reliance on the internal-combustion engine in various markets around the globe, including the U.S.[48,49] These goals and investments have been coupled with a continuing increase in the market penetration of new zero-emission vehicles (3.6 percent of new U.S. light-duty vehicle sales so far in calendar year 2021,[50] and projected to be 4.1 percent of production in MY 2021 up from 2.2 percent of production in MY 2020),[51] as well as a rapidly increasing diversity of plug-in vehicle models in the U.S.[52] For example, the number of battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) models available for sale in the U.S. has more than doubled from about 24 in MY 2015 to about 60 in MY 2021, with offerings in a growing range of vehicle segments.[53,54] Recent model announcements indicate that this number will increase to more than 80 models by MY 2023, with many more expected to reach production before the end of the decade.[55] Market forecasts suggest a combined EV and PHEV (including range-extended EV) sales share of approximately 16 percent to 24 percent in the U.S. by 2026,[56,57] which compare favorably to the ZEV projection for this final rule. Many of the ZEVs already on the market today cost less to drive than conventional vehicles,[58,59] offer improved performance and handling,[60] and can be charged at a growing network of public chargers as well as at home.[61]

Recent BEV product announcements also include a growing number of dedicated battery electric vehicle platforms, such as the GM BEV2 light-duty vehicle (LDV) and BEV3 light-duty-truck (LDT) platforms, the Tesla Model 3/Model Y LDV and crossover utility vehicle (CUV) platform, the VW MEB LDV and CUV platform, and the Hyundai E-GMP LDV and CUV platform.[62] Dedicated BEV platforms eliminate provisions for internal combustion engine (ICE) powertrain, exhaust emissions, evaporative emissions, and fuel systems that would otherwise need to be accommodated on platforms that are shared between BEV, PHEV, HEV, and conventional ICE vehicle models. This dedicated BEV platform approach typically allows integration of the battery pack entirely within the vehicle floor structure, reduces vehicle weight, reduces manufacturing costs, increases available passenger and cargo volume, and in some cases, has the battery pack integrated as part of the vehicle's crash mitigation structure.

An increasing number of global jurisdictions and U.S. states are planning to take actions to shift the light-duty fleet toward zero-emissions technology. In 2020, California announced an intention to require increasing volumes of ZEVs to meet the goal that, by 2035, all new light-duty vehicles sold in the state be ZEVs.[63] New York has adopted similar targets and requirements to take effect by 2035, [64,65] with Massachusetts poised to follow.[66] Several other states may adopt similar provisions by 2050 as members of the International Zero-Emission Vehicle Alliance.[67] Globally, at least 12 countries, as well as numerous local jurisdictions, have announced similar goals to shift all new passenger car sales to ZEVs in the coming years, including Norway (2025), the Netherlands, Denmark, Iceland, Ireland, Sweden, and Slovenia (2030), Canada and United Kingdom (2035), France and Spain (2040) and Costa Rica (2050).[68,69] Together, these countries represent approximately 13 percent of the global market for passenger cars, in addition to that represented by the aforementioned U.S. states and other global jurisdictions.[70]

2.3.4 Automotive Li-ion Battery Costs

In response to numerous stakeholder comments (see Preamble III.A), EPA reviewed the battery costs used in the SAFE rulemaking, which had been carried over to the analysis for the proposal. We considered the inputs that had previously been used to derive the costs, and compared those costs to estimates we had derived in previous and ongoing analyses and to the current and expected future costs of batteries as widely reported in the trade and academic literature. We concluded that the battery costs used in the proposal were significantly higher than indicated by this evidence, and that the likely effect of using an updated set of assumptions would be more in agreement with the emerging consensus on the level and direction of battery costs within the industry.

Based on an assessment of the effect of using updated inputs in place of those used in the SAFE rulemaking, we found technical justification for reducing battery costs by approximately 25 percent. Details on the technical basis for this change can be found in Section 4.1.1.2 of this RIA.

We also considered the effect of this reduction on the projected battery costs for future years beyond the time frame of the rule. Applying the existing learning curve to the downward adjusted costs past the time frame of the rule would produce costs gradually declining to below $80 per kWh (for an example 60 kWh battery) in the mid-2030s and to about $75/kWh by the mid-2040s. EPA is currently uncertain about the potential for battery costs to reach this level due in part to uncertainties about the effect of increased demand for critical minerals and other factors, which we also received comment on, and also because our current battery modeling tools such as BatPaC 4.0 are unable to generate costs at these levels using inputs that can reasonably be validated. Due to the widely acknowledged uncertainty of quantitatively projecting declines in battery costs far into the future, and particularly in the context of the downwardly adjusted battery costs, we chose to flatten the rate of learning past 2029 so as to prevent future costs from declining below $90 per kWh for a 60 kWh battery, a level that we can technically validate at this time. More information on the technical basis for this change can be found in Section 4.1.1.2 of this RIA.

We believe that holding learning constant after 2029 is likely a conservative assumption, as we continue to expect that some level of continued learning will occur beyond 2029 but there is uncertainty at this point on what the appropriate level of learning would be. Thus, our battery cost estimates beyond 2029 in this final rulemaking may be conservatively high. EPA continues to study the potential for cost reductions in batteries during and after the time frame of the rule. For example, we expect that pending updates to the ANL BatPaC model, as well as collection of emerging data on forecasts for future mineral prices and production capacity, will make it possible to characterize the rate of decline in battery costs that we continue to believe will occur from 2030 to 2050, as well as trends in costs in the nearer term, and we will incorporate this information in the subsequent rulemaking for MYs 2027 and beyond. For more discussion please see Section 4.1.1.2 of this RIA.

2.4 Analysis of Manufacturers Generation and Use of GHG Credit

EPA believes that the multi-year nature of auto design and development means that the industry’s product plans originally developed in response to the EPA’s 2012 GHG standards rulemaking for MYs 2017-25 have largely continued notwithstanding the SAFE rule that was promulgated in April 2020, including relaxed standards beginning in MY 2021. Thus, in most cases, the vehicles that automakers will be producing during the first years of the Final MY 2023-26 program were already designed under the original, more stringent GHG standards for those model years finalized in 2012. Manufacturers are also already demonstrating the ability to comply with the Final 2023 model year standards with many vehicles currently for sale.

For the Final Rule, EPA performed an analysis of 2021 model year vehicles to assess how changes in sales mix could help facilitate vehicle manufacturer compliance to more stringent standards. This analysis examined certification and projected sales data for 2021 model year vehicles. EPA assumed that manufacturers continue to utilize credits for off-cycle technologies, as well as A/C credits for reduced refrigerant leakage and improved efficiency. The level of off-cycle credits was based on average manufacturer's MY 2019 off-cycle credits for cars and trucks, respectively (so it does not reflect the Final Rule's increased cap to 15 g/mi of menu off-cycle credits). EPA applied the industry average of 19 g/mi and 24 g/mi of total A/C credits for car and truck models, respectively, to each manufacturer. Table 2-6 and Table 2-7 show the availability of "credit generators" (the number of unique vehicle models that outperform their revised individual footprint-based standard for 2023 model year), grouped by market segment. The smallest market segments, by total sales volume, are shaded in gray and collectively represent only about 5 percent of all sales. Projected performance is based on actual 2021 tailpipe CO_2 emissions and adjusting for assumed A/C and off-cycle credits.

The analysis accounted for the various trim levels by manufacturers, as there are 1370 unique vehicle model types in the 2021 model year. Of those 1370 unique vehicles, 216 models (over 16 percent of all models sold) already outperform the revised 2023 standards. 125 of these models are advanced gasoline or hybrid vehicles while an additional 91 models are plug-in hybrids or battery electric vehicles.

Table 2-6: Distribution of 2021 MY Vehicle Models and Number of Vehicles Which Generate Credits vs. 2023 MY Standards (All Vehicles)

Vehicle Category	Total Models	Credit Generators	Mkt Segment % of 2021 Sales
Minicompact Cars	35	1	0%
Subcompact Cars	119	9	2%
Compact Cars	116	15	6%
Two Seaters	64	0	0%
Midsize Cars	158	28	13%
Large Cars	87	21	5%
<Small Station Wagons	31	12	3%
Midsize Station Wagons	12	0	0%
Minivans	8	3	2%
Vans	16	0	1%
Small SUVs	140	32	28%
Standard SUVs	288	34	25%
Small Pick-up Trucks	40	0	3%
Standard Pick-up Trucks	256	61	13%
Totals	1370	216	
Gray shading denotes niche vehicle segments at or below 3 percent of total sales			

Table 2-7: Distribution of 2021 MY Vehicle Models and Number of Vehicles Which Generate Credits vs. 2023 MY Standards (Gasoline ICE and Hybrid Vehicles)

Vehicle Category	Total Models	Credit Generators	Mkt Segment % of 2021 Sales
Minicompact Cars	34	0	0%
Subcompact Cars	110	0	2%
Compact Cars	107	6	6%
Two Seaters	63	0	0%
Midsize Cars	143	13	13%
Large Cars	70	7	5%
Small Station Wagons	22	3	3%
Midsize Station Wagons	12	0	0%
Minivans	7	2	2%
Vans	16	0	1%
Small SUVs	131	23	28%
Standard SUVs	264	10	25%
Small Pick-up Trucks	40	0	3%
Standard Pick-up Trucks	256	61	13%
Totals	1275	125	
Gray shading denotes niche vehicle segments at or below 3 percent of total sales			

Some niche market segments (shaded in gray within Table 2-6 and Table 2-7) including the smallest vehicles (minicompact and subcompact cars), two-seaters, and small pickup trucks - show few or no credit-generating models. However, credit-generators are currently available to manufacturers in market segments that represent nearly 95 percent of the total sales volume.

Using the same analytical approach, these 2021 vehicle models offer additional credits and more opportunities against the 2022 model year standards (Table 2-8). It is evident that manufacturers are already well-positioned to earn significant credits against the 2022 model year standards (and thus, also against the 2021 standards) with their 2021 vehicles. These credits can be banked to provide margin for later years as a potential compliance strategy.

Table 2-8: Distribution of 2021 MY Vehicle Models and Number of Vehicles Which Generate Credits vs. 2022 MY Standards (All Vehicles)

Vehicle Category	Total Models	Credit Generators	Market Segment % of 2021 Sales
Minicompact Cars	35	1	0%
Subcompact Cars	119	9	2%
Compact Cars	116	25	6%
Two Seaters	64	0	0%
Midsize Cars	158	40	13%
Large Cars	87	29	5%
Small Station Wagons	31	14	3%
Midsize Station Wagons	12	0	0%
Minivans	8	5	2%
Vans	16	8	1%
Small SUVs	140	52	28%
Standard SUVs	288	61	25%
Small Pick-up Trucks	40	0	3%
Standard Pick-up Trucks	256	92	13%
Totals	1370	336	
Gray shading denotes niche vehicle segments at or below 3 percent of total sales			

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Chapter 3: Economic and Other Key Inputs

3.1 Rebound

3.1.1 Accounting for the Fuel Economy Rebound Effect

In the context of light-duty vehicles (LDVs), rebound effects might occur when an increase in vehicle fuel efficiency results in individuals driving more as a result of the lower cost per mile of driving. Because this additional driving consumes fuel and generates emissions, the magnitude of the rebound effect is one determinant of the actual fuel savings and emission reductions that will result from adopting GHG emissions standards. The rebound effect generally refers to the additional energy consumption that may arise from the introduction of a more efficient, lower cost energy service. This effect offsets, to some degree, the energy savings benefits of that efficiency improvement.[1,2,3]

The rebound effect for personal vehicles can, in theory, be estimated directly from the change in vehicle use, in terms of vehicle miles traveled (VMT), which results from a change in vehicle fuel efficiency.[a] In practice, any attempt to quantify this "VMT rebound effect" (sometimes also labeled the "direct rebound effect," or "direct VMT rebound effect") is complicated by the difficulty in identifying an applicable data source from which the response to a significant improvement in fuel efficiency can be estimated.[b,4] Analysts, instead, often estimate the VMT rebound indirectly, as the change in vehicle use that results from a change in fuel cost per mile driven or a change in fuel price. When a fuel cost per mile approach is used, it does not distinguish the relative contributions of changes in fuel efficiency and changes in fuel price to the rebound effect, since both factors are determinants of fuel cost per mile.[c] When expressed as positive percentages, the elasticities give the percentage increase in vehicle use that is presumed to result from an increase in fuel efficiency or a decrease in fuel price.

The VMT rebound effect can also be divided into: (1) the short- to medium-run and (2) the long-run rebound effect. Typically, studies estimating the short- to medium-run VMT rebound effect are based upon a time period of roughly one to two years when the vehicle stock and land use patterns are not changing significantly. The long-run rebound effect is estimated over a longer time period when households can adjust where they work and live and the vehicle stock can change more significantly than in the short/medium-run time frame. It is oftentimes difficult to directly identify a long-run rebound effect, as many factors influencing travel behavior are also changing over time. Thus, many VMT rebound estimates in the transportation policy and economics literature are based on short- and medium-run responses because these responses are easier to identify. Ideally, the evolution of VMT rebound effects over time from short- and

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[a] Vehicle fuel efficiency is sometimes measured in terms of fuel consumption (gallons per mile) rather than fuel economy (miles per gallon) in rebound estimates.

[b] Many of time series studies of the LDV rebound effect examine time periods before 2010. U.S. LDV fleet-wide fuel economy has only been increasing since 2005. From 2005 to 2010, U.S. LDV fleet-wide fuel economy improvements were fairly modest. Thus, there may be insufficient variability in LDV fuel economy to estimate a relationship between fuel economy and VMT. See reference citation [4].

[c] Fuel cost per mile is equal to the price of fuel in dollars per gallon divided by fuel economy in miles per gallon (or multiplied by fuel consumption in gallons per mile), so this figure declines when a vehicle's fuel efficiency increases.

medium-run effects to long-run effects would be utilized in an analysis of LDV GHG standards. However, there is not a sufficient understanding of the evolution of VMT rebound effects over time to incorporate this pattern in this final rule.

While we focus on the VMT rebound effect in our analysis of this LDV final rule, there are at least two other types of rebound effects discussed in the transportation policy and economics literature: the "indirect rebound effect," which typically refers to the purchase of other energy-consuming goods or services using the cost savings from energy efficiency improvements, and the "economy-wide rebound effect." The economy-wide rebound effect refers to the increased demand for energy throughout the whole economy, in response to the reduced market price of energy that results from energy efficiency improvements.

Because research on indirect and economy-wide rebound effects is scant, the rebound effect discussed in this section refers solely to the effect of increased fuel efficiency on vehicle use. The terms "VMT rebound effect," "direct VMT rebound effect," and "rebound effect" are used interchangeably, and are distinguished from other rebound effects that could potentially impact the fuel savings and emissions reductions from EPA's final LDV standards, including the indirect and the economy-wide rebound effects.[d]

3.1.2 Summary of Historical Literature on the LDV Rebound Effect

This section provides a brief summary of historical literature on the LDV rebound effect. It is important to note that a majority of the studies previously conducted rely on data from the 1950 –1990s. While these older studies provide useful information on the potential magnitude of the rebound effect, studies based on more recent information (e.g., within the last decade) provide more applicable estimates of how the final LDV standards will affect future driving behavior. A number of more recent studies on LDV rebound effects (i.e., after 2010) are summarized in Section 3.1.3 below.

Estimates from published studies covering the period from roughly 2010 and earlier using data from 1950–2004 have found long-run rebound effects on the order of 10–30 percent. Some of these studies are summarized in Table 3-1 and Table 3-2. In addition, Table 3-3 provides estimates of the rebound effect using U.S. household survey data.

Table 3-1: Estimates of the Rebound Effect Using U.S. Aggregate Time-Series Data on Vehicle Travel

Author (year)	Short-Run	Long-Run	Time Period
Mayo & Mathis (1988)	22%	26%	1958-1984
Gately (1992)	9%	9%	1966-1988
Greene (1992)	Linear 5-19% Log-linear 13%	Linear 5-19% Log-linear 13%	1957-1989
Jones (1992)	13%	30%	1957-1989
Schimek (1996)	5-7%	21-29%	1950-1994
Source: Sorrell and Dimitropolous (2007) Table 4.6.[5]			

[d] The indirect and economy-wide rebound effects do not justify applying a rebound rate higher than 10 percent in this analysis. These additional rebound effects, to the extent they exist, may be small and their contribution to the overall rebound rate would be offset by other considerations discussed below, such as how future GDP could reduce the VMT rebound rate and how consumers' total VMT may be more responsive to salient changes in fuel prices than to gradual reductions in fuel costs per mile from these LDV GHG standards.

Table 3-2: Estimates of the Rebound Effect Using U.S./State and Canadian/Province Level Data

Author (year)	Short-Run	Long-Run	Time Period
Haughton & Sarkar (1996)	9-16%	22%	1973-1992
Small and Van Dender (2007)	5% 2%	22% 11%	1966-2001 1997-2001
Hymel, Small and Van Dender (2010)	3% 5%	14% 16%	1966-2004 1984-2004
Barla et al. (2009)	8%	18%	1990-2004
Source: Sorrell and Dimitropolous (2007) Table 4.7, with the addition of Small and Van Dender (2007), Hymel, Small and Van Dender (2010) and Barla et al. (2009). The Barla et al. study is based upon Canadian Province data.			

Table 3-3: Estimates of the Rebound Effect Using U.S. Household Survey Data

Author (year)	Estimate of Rebound Effect	Time Period
Goldberg (1996)	0%	1984-1990
Greene, Kahn, and Gibson (1999)	23%	1979-1994
Pickrell & Schimek (1999)	4-34%	1995
Puller & Greening (1999)	49%	1980-1990
West (2004)	87%	1997
Source: Sorrell and Dimitropolous (2007).		

While studies using national (Table 3-1) and state-level (Table 3-2) data have found a relatively consistent range of long-run estimates of the rebound effect, household surveys display more variability (Table 3-3). One explanation for this variability is that these studies consistently find that the magnitude of the rebound effect differs according to the number of household vehicles, and the average number of household vehicles differs among the surveys used to derive these estimates. Still another possibility is that it is difficult to distinguish the impact of fuel cost per mile on vehicle use from other, unobserved factors. For example, commuting distance might influence both the choice of the vehicle and VMT. Residential density may also influence both fuel cost per mile and VMT since households in urban areas are likely to simultaneously face both higher fuel prices and shorter travel distances. Also, given that household data tends to be collected on an annual basis, there may not be enough variability in the fuel price data to estimate the magnitude of the rebound effect.[6]

Since there has been little variation in fuel economy over the time frame of most studies, isolating the impact of fuel economy on VMT can be difficult using econometric analysis of historical data. Therefore, studies that estimate the rebound effect using time series data often examine the impact of gasoline prices or fuel cost per mile (i.e., the combined impact of both gasoline prices and fuel economy) on VMT. However, if drivers are more responsive to changes in fuel price or the cost of driving than to the variable directly of interest, fuel economy, these studies may overstate the potential impact of the rebound effect resulting from this final rule. For example, drivers may respond more to changes in fuel prices that are highly visible (i.e., salient) than to changes in fuel economy from vehicle standards that are gradually implemented over time.

Another important distinction among studies is whether they assume that the rebound effect is constant or varies over time in response to the absolute levels of fuel costs, personal income, or household vehicle ownership. Most studies using aggregate annual data for the U.S. assume a constant rebound effect, although some test whether the effect can vary as changes in retail fuel prices or average fuel efficiency alter fuel cost per mile driven. Many studies using household survey data estimate significantly different rebound effects for households owning varying numbers of vehicles, with most finding that the rebound effect is larger among households that own more vehicles.

Some of the studies, such as Small and Van Dender (2007) and Hymel, Small and Van Dender (2010), using a combination of state-level and national data, conclude that the rebound effect varies directly in response to changes in personal income, as well as fuel costs. These studies indicate that the rebound effect has decreased over time as incomes have risen. One reason that the rebound effect could vary over time is that the responsiveness to the fuel cost of driving will be larger when it is a larger proportion of the total cost of driving. For example, as incomes rise, the responsiveness to the fuel cost per mile of driving will decrease if households view the time cost of driving – which is likely to be related to their income levels – as a larger component of the total cost.

Small and Van Dender (2007) combine time series data for each of the 50 states and the District of Columbia to estimate the rebound effect, allowing the magnitude of the rebound to vary over time.[7] For the time period 1966–2001, their study finds a long-run rebound effect of 22 percent, which is generally consistent with previously published studies.[e] But for the five-year period (1997–2001) estimated in their study, the long-run rebound effect decreases to 11 percent. Hymel, Small and Van Dender (2010) extend the Small and Van Dender model by adding congestion's impact on driving behavior.[8] Controlling for congestion modestly increases their estimates of the rebound effect in the study. For the time period 1966–2004, they estimate a long-run rebound effect of 14 percent. For the time period, 1984–2004, they find a long-run rebound effect of 16 percent, while for the most recent year in their data set, 2004, they estimate a long-run rebound effect of 9 percent.

Barla et al. (2009) uses Canadian, province-level, panel data from 1990–2004 of light-duty vehicles to estimate a VMT rebound effect.[9] The model uses a similar methodological approach as Small and Van Dender (2007) use, with a simultaneous three-equation model of aggregate demand for vehicle kilometers traveled, vehicle stock and fuel efficiency. Barla et al. find short- and long-run VMT rebound effects of 8 percent and 18 percent, respectively.[f]

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[e] The Small and Van Dender (2007) methodology uses a lagged dependent variable to calculate a long-run rebound estimate. The idea is that by using the coefficient on the lagged dependent variable, the speed of adjustment can be utilized to develop an estimate of the long-run equilibrium rebound value. In follow-on studies, Hymel, Small and Van Dender (2010) and Hymel and Small (2015) use the same methodology to estimate a long-run VMT rebound effect.

[f] Barla et al. (2009), using a methodology similar to Small and Van Dender (2007), break out short-run from long-run VMT rebound effects.

There is some evidence in the literature that consumers are more responsive to an increase in fuel prices than to a decrease in fuel prices. At the aggregate level, Dargay and Gately (1997) and Sentenac-Chemin (2012) provide some evidence that demand for transportation fuel is asymmetric.[10] In other words, given the same magnitude of change, the response to a decrease in gasoline price is smaller than the response to an increase. Gately (1993) shows that the response to an increase in oil prices can be on the order of five times larger than the response to a price decrease.[11] Furthermore, Dargay and Gately and Sentenac-Chemin also find evidence that consumers respond more to a large shock than to a small, gradual change in fuel prices. Since these final standards would decrease the cost of driving gradually over time, it is possible that the rebound effect would be much smaller than some of the historical estimates included in the literature.

3.1.3 <u>Review of Recent Literature on LDV Rebound</u>

More recent studies on LDV rebound effects have become available in the last decade (i.e., since 2010) and are summarized in Section 3.1.3 below. Most of the VMT rebound estimates reported in this section are short- and medium-run estimates.

A national, U.S. study by Greene (2012) concludes that the magnitude of the rebound effect "is by now on the order of 10 percent."[12] In this study, Greene looks at how VMT is influenced by the gasoline price fluctuations, light-duty fuel consumption patterns, U.S. real personal income, and the number of registered vehicles in the U.S., among other factors. Over the entire time period analyzed, 1966–2007, Greene finds that fuel prices have a statistically significant impact on VMT, while fuel efficiency did not. From this perspective, if the impact of fuel efficiency on VMT is not statistically significant, the VMT rebound effect could be zero. Like Small and Van Dender, Greene finds that the VMT rebound effect is declining modestly over time as household incomes rise and travel costs increase. When using Greene’s preferred functional form, the projected rebound effect is approximately 12 percent in 2008, and drops to 10 percent in 2020 and to 9 percent in 2030.

Using data on household characteristics and vehicle use from the 2009 NHTS, Su (2012) analyzes the effects of locational and demographic factors on household vehicle use and investigates how the magnitude of the rebound effect varies with vehicles’ annual use.[13] Using variation in the fuel economy and per-mile cost of driving and detailed controls for the demographic, economic, and locational characteristics of the households that owned them (e.g., road and population density) and each vehicle’s main driver (as identified by survey respondents), Su employs specialized regression methods to capture the variation in the rebound effect across ten different categories of vehicle use.

Su estimates that the overall rebound effect for all vehicles in the sample averages 13 percent, and that its magnitude varies from 11–19 percent among the ten different categories of annual vehicle use. The smallest rebound effects were estimated for vehicles at the two extremes of the distribution of annual use – those vehicles driven comparatively little, and those vehicles used most intensively – while the largest estimated effects applied to vehicles that were driven slightly more than average. Controlling for the possibility that high-mileage drivers respond to the increased importance of fuel costs by choosing vehicles that offer higher fuel economy narrowed the range of Su’s estimates of rebound effects slightly (to 11–17 percent) but did not alter the finding that they are smallest for lightly- and heavily-driven vehicles and largest for those with slightly above average use. The 2009 NHTS is based upon data collected from April 2008 to

April 2009. This time period may have been an unusual time period, since it was during the time period of the Great Recession. It is not clear how the impacts of employment and output losses from the Great Recession influenced, and resulted in, unusual travel patterns in the U.S.

Frondel and Vance (2013) use panel estimation methods and household diary travel data collected in Germany between 1997–2009 to identify an estimate of a private transport rebound value.[14] The study focuses on single-car households that did not change their car ownership over the timeframe each household was surveyed, up to a maximum of three years. Frondel and Vance find a rebound effect for single-vehicle households of 46–70 percent.

Liu et al. (2014) employ the 2009 NHTS to develop an elaborate model of an individual household's choices about how many vehicles to own, what types and ages of vehicles to purchase, and how much combined driving to do using all of the household's vehicles for the D.C. Metro area.[15] Their analysis uses a complex mathematical formulation and statistical methods to represent and measure the interdependence among households' choices of the number, types, and ages of vehicles to purchase, as well as how intensively to use them. The complexity of the relationships among a number of factors incorporated in their model – the number of vehicles owned, their specific types and ages, fuel economy levels, and use – requires them to measure these effects by introducing variation in income, neighborhood attributes, and fuel costs, and observing the response of households' annual driving. Their results imply a rebound effect of approximately 40 percent in response to a significant (25–50 percent) variation in fuel costs, with almost exactly symmetrical responses to increases and declines in fuel costs.

Like Su and Liu et al., Linn (2016) also uses the 2009 NHTS to develop an approach to estimate the relationship between the VMT of vehicles belonging to each household and a variety of different factors: fuel costs, vehicle characteristics other than fuel economy (e.g., horsepower, the overall "quality" of the vehicle), and household characteristics (e.g., age, income).[16] Linn reports a fuel economy rebound effect with respect to VMT of between 20–40 percent.

One interesting result of the study is that when the fuel efficiency of all vehicles on the road increases – which would be the long-run effect of rising fuel efficiency standards – two factors have opposing effects on the VMT of a particular vehicle in a multi-vehicle household. First, VMT increases when a vehicle's own fuel economy increases. But the increase in fuel economy of the household's other vehicles cause the vehicle's own VMT to decrease. Since the vehicle's own VMT response to a fuel economy increase is larger in magnitude than the VMT response to changes in other vehicles' fuel economy, VMT increases if the fuel economy of all vehicles increases proportionately. Linn also finds that VMT responds much more strongly to vehicle fuel economy than to gasoline prices, which is at variance with the Hymel et al. and Greene results discussed above.

Gillingham (2014) examines a period of significant swings in retail gasoline prices, along with media reports of changing household driving habits, to examine how households respond to changes in gasoline prices.[17] This study uses a vehicle-level dataset of all new vehicles registered in California in 2001–2003, and subsequently given a smog check (i.e., odometer readings) over the 2005–2009 time frame, a period of steady economic growth but rapidly increasing gasoline prices. Gillingham estimates the effect of differences in average monthly fuel price on monthly vehicle use – at a county level. The primary empirical result of the responsiveness of new vehicle VMT to gasoline prices is a medium-run estimate of 22 percent. There is evidence of considerable heterogeneity in this responsiveness across buyer types, demographics, and geographic conditions.

In a follow-up paper, Gillingham (2020) states that this 2014 study examines the response to the 2008 gasoline price shock in California, an unusual period when gasoline prices were particularly salient to consumers.[18] Thus, according to Gillingham, the results of his 2014 study should not be used for developing an estimate of the VMT rebound effect for fuel economy/GHG standards. Gillingham points to his own PhD dissertation (2011) which examines travel patterns for California drivers from 2001 to 2009 using odometer readings as more suggestive of the VMT rebound effect of LDV fuel economy/GHG standards.[19] His PhD estimates a VMT rebound effect of one percent.

Gillingham's results in his 2014 paper find that vehicle-level responsiveness to fuel price increases with income, which is the opposite of the conclusions that Hymel, Small and Van Dender and Greene find in previous studies. Gillingham hypothesizes that the increase in the per-vehicle rebound effect with higher incomes may relate to wealthier households having more discretionary driving, or to switching between flying and driving. Alternatively, wealthier households tend to own more vehicles, and it is possible that within-household switching of vehicles may account for the greater responsiveness at higher income levels.

Wang and Chen (2014) examine the responsiveness of VMT to fuel prices across income groups, using a system of structural equations with VMT and fuel efficiency (i.e., miles per gallon) from the 2009 NHTS.[20] They find that the rebound effect is only significant for the lowest income households (up to $25,000). Wang and Chen hypothesize that low-income households have numerous unfilled travel needs. Thus, fuel efficient vehicles spur more driving by low-income households.

Hymel and Small (2015) revisit the simultaneous equations methodology of Small and Van Dender (2007) and Hymel, Small and Van Dender (2010), to see whether their previous estimates of the VMT rebound effect have changed by adding in more recent data (2005–2009).[21] Their estimates of the long-run light-duty vehicle rebound effect over 2000–2009 are 4–18 percent, when evaluated at average values of income, fuel cost, and urbanization in the U.S. during this time period. However, these results also show strong evidence of asymmetry in responsiveness to fuel price increases and decreases. Results suggest that a rebound adjustment to fuel price rises takes place quickly; the rebound response is large in the year of, and the first year following, a price rise, then diminishes to a smaller value. The rebound response to price decreases occurs more slowly.

One commenter (Center for Biological Diversity, et al.) suggests that while EPA's proposed rule reports a range of VMT rebound estimates from the Hymel and Small (2015) study of 4 to 18 percent, that only the lower value of the range, 4 percent, should be used in developing an estimate of the VMT rebound effect for use in this rule. The basis for this commenters' suggestion is a statement by Small in the context of the SAFE rule that: "A better characterization of the most recent study would be that it finds a long-run rebound effect of 4.0 percent or 4.2 percent under two more realistic models that are supported by the data".[g] The 18 percent VMT rebound estimate in this study is based upon a model that does not consider

[g] See Small, Kenneth, Comment Letter on Proposed MY 2021-2026 Standards, 2018.

whether drivers respond asymmetrically to increases or decreases in fuel prices/cost of driving, which Small labels his "base model". According to Small, the base model is the starting point for the development of asymmetric models which are the main objective of the paper. In the new models that Hymel and Small develop in the paper, they find asymmetric responses to fuel price/fuel cost changes. In other words, drivers respond more to fuel price/cost of driving increases as compared to fuel price/cost of driving decreases. Since this rule will result in increases in vehicle fuel economy which lowers the cost of driving, the applicable VMT rebound estimate is 4 percent. To summarize, we agree with the commenter that the 4 percent VMT rebound value is more applicable than other estimates from this study for estimating a VMT rebound effect for this rule.

Consistent with previous results using the same modeling framework used previously in their other published studies, Small et al. find that the VMT rebound effect declines with increasing income and urbanization and increases with increasing fuel cost. By far the most important of these sources of variation is income, the effect of which is large enough to reduce the projected rebound effect for time periods of interest for this final rule.

The study by Hymel and Small also finds a strengthening of the VMT rebound effect for the years 2003–2009 when compared to their earlier results, suggesting that some additional, unaccounted for factors have increased the rebound effect. Three potential factors are hypothesized to have caused the upward shift in the VMT rebound effect in the 2003–2009 time period: (1) media coverage, (2) price volatility, and (3) asymmetric responses to fuel price changes.[h] While media coverage and volatility are important for understanding the rebound effect based upon fuel prices, they may not be as relevant to influencing the rebound effect due to fuel efficiency from LDV standards.

Hymel and Small find that there is an upward shift in the rebound effect of 2.5–2.8 percent starting in 2003. Results suggest that the media coverage and volatility variables may explain about half of the upward shift in LDV rebound in the 2003–2009 time period. Nevertheless, these influences are small enough that they do not fully offset the downward trend in VMT response due to higher incomes and other factors. Hence, even assuming the variables retain their 2003–2009 values into the indefinite future, they will not prevent a further diminishing of the magnitude of the rebound effect if incomes continue to grow through time.

West et al. (2017) attempt to estimate the VMT rebound effect with household level data from Texas, using a discontinuity in the eligibility requirements for the 2009 U.S. Car Allowance Rebate System (CARS). This program, known as “Cash for Clunkers,” incentivized eligible households to purchase more fuel-efficient vehicles.[22] Households that owned “clunkers” – defined as vehicles with a fuel economy of 18 miles per gallon (MPG) or less – were eligible for the subsidy, as long as their replacement vehicle was at least 22 MPG. The empirical strategy of the paper is to compare the fuel economy of vehicle purchases and subsequent VMT of “barely eligible” households to those households who were “barely ineligible.”

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[h] The media coverage variable is measured by constructing measures of media coverage based upon gasoline-price related articles appearing in the New York Times newspaper. Using the ProQuest historical database, they tally the annual number of article titles containing the words gasoline (or gas) and price (or cost). They then form a variable equal to the annual fraction of all New York Times articles that are gasoline-price-related. This fraction ranged from roughly 1/4000 during the 1960s to a high of 1/500 in 1974.

Based upon odometer data reporting VMT, the paper finds a meaningful discontinuity in the fuel economy of new vehicles purchased by CARS-eligible relative to ineligible households. West et al. report that the increases in fuel economy realized by households who utilized the program were not accompanied by increased use of the higher-MPG replacement vehicles. They suggest this is because of the replacement vehicles' other attributes. Because households chose to buy cheaper, smaller, and lower-performing vehicles, they did not drive any additional miles after the purchase of the fuel-efficient vehicle. They conclude there is no evidence of a rebound effect in response to improved fuel economy from the CARS program.

It is difficult to generalize the VMT response from the CARS program to a program for LDV GHG standards. This was a one-time program for a fixed fleet of existing vehicles with specific characteristics. The change in vehicle attributes from the program may not be representative of any vehicle attribute changes from LDV GHG standards. Thus, this study does not provide useful implications about the likely response of vehicle use to increases in LDV GHG standards.

Gillingham et al. (2015) use detailed annual vehicle-level emissions inspection test data from Pennsylvania for 2000–2010 – including odometer readings, inspection zip codes, and extensive vehicle characteristics – to examine both the responsiveness of driving to changing gasoline prices, and heterogeneity in this responsiveness by geography, the fuel economy of the vehicle, and the age of the vehicle.[23] The study finds a short-run driving response (i.e., VMT) to gasoline prices of 10 percent.

Leung (2015) examines how VMT is allocated across a typical household's vehicles in response to a gasoline price increase.[24] Leung uses 2009 NHTS data to decompose household decreased demand for gasoline in response to a gasoline price increase into: (1) changes to VMT and (2) changes to fuel economy or MPG (via a household reallocating its VMT to a vehicle with a different MPG). Leung finds a VMT responsiveness to gasoline prices of 10 percent.

Langer et al. (2017) develop a model of motorists' demand for automobile travel that explicitly accounts for heterogeneity across drivers and their vehicles for the state of Ohio. The study estimates drivers' responses to changes in the marginal cost of driving. The study is based upon data from State Farm Mutual Automobile Insurance Company on individual drivers who, in return for a discount on their insurance, allowed a private firm to remotely record their vehicles' VMT from odometer readings from 2009–2013. The model allows for a comparison of the effects of gasoline and VMT taxes on fuel consumption, among other factors. They find a responsiveness of VMT with respect to the price of automobile travel is 12 percent.[25]

Knittel and Sandler (2018) estimate the VMT responsiveness to gasoline price, in the context of the gasoline tax as an emission reduction policy tool. The study looks at California LDVs over the period of 1998−2008, using odometer readings (i.e., Smog Check data).[26] They find an average VMT responsiveness of 13 percent. They also observe significant heterogeneity across different types of vehicles, suggesting that VMT responsiveness to gasoline prices can vary significantly based upon the specific sub-classes of vehicles considered.

One interesting study of VMT rebound is by De Borger et al. (2016). They analyze the response of vehicle use to changes in fuel economy among a sample of nearly 350,000 Danish households owning a single vehicle, of which almost one-third replaced it with a different model during the 2001–2011 time period.[27] By comparing the change in households' driving between those who replaced their vehicles during the intervening period to those who did not, the authors attempt to isolate the effect of changes in fuel economy on vehicle use from those of other factors. Their data allow them to control for the effects of household characteristics and vehicle features other than fuel economy on vehicle use. The authors use complex statistical methods to account for the fact that some households replacing their vehicles may have done so in anticipation of changes in their driving demands (rather than the reverse), as well as for the possibility that some households who replaced their vehicles may be doing so because their driving behavior is more sensitive to fuel prices than other households.

De Borger et al. measure the rebound effect from the change in households' vehicle use in response to changes in fuel economy that are a consequence of their decisions to replace their vehicles. Thus, the authors directly estimate the fuel economy rebound effect itself, in contrast to studies that rely on indirect measures, such as fuel prices or the costs per mile of driving. Their preferred estimates of the fuel economy rebound effect range from 8–10 percent. De Borger et al. also find no evidence that the rebound effect is smaller among lower-income households than among their higher-income counterparts.

Gillingham et al. (2016) undertake a summary and review of the general rebound literature, including rebound effects from LDV studies considered for this final rule, as well as electricity used in stationary applications.[28] According to Gillingham et al., the literature suggests that differences in estimates of the rebound effect stem from its varying definitions, as well as variation in the quality of data and empirical methodologies used to estimate it. Gillingham et al. seek to clarify the definition of each of the channels of the rebound effect, and to critically assess the state of the literature that estimates its magnitude.

Gillingham et al. note that most analyses assume a "zero cost breakthrough" (ZCB) – their term for an improvement in efficiency that results in energy savings and related energy or fuel cost savings but does not have associated increased costs of technology or implementation. Thus, the authors argue, most analyses do not reflect the true costs of a "policy-induced improvement." Gillingham et al. also caution that failing to account for the increased costs of equipment and/or implementation of a policy-induced improvement may result in different estimates of the rebound effect, compared to a ZCB improvement in efficiency.

Wenzel and Fujita (2018) examine the responsiveness of driving to changes in the price of gasoline and driving costs.[29] Using detailed odometer readings from over 30 million vehicles in four urban areas of Texas from 2005–2010, they estimate that the responsiveness of the demand for VMT with respect to the price of gasoline in Texas is 9 percent, after accounting for differences in vehicle models. They also use the rated combined city/highway fuel economy of each vehicle to calculate the cost of driving, in cents per mile, since a vehicle's previous inspection. They find a VMT responsiveness with respect to the cost of driving of 16 percent.

A study by Gillingham and Munk-Nielsen (2019) provides an estimate for the fuel price elasticity of driving for Denmark in the period from 1998−2011.[30] They find a one-year elasticity of 30 percent. An interesting aspect of this study is that it finds two tails of more responsive drivers. The first tail is drivers living in the outskirts of cities with long commutes, but with adequate access to public transport. The second tail is composed of drivers who commute very little and tend to live in cities. Households with long commutes can readily switch to public transport, while households who commute very little largely use their vehicles for a diverse set of non-work trips, many of which can be readily switched to other modes of transport.

The finding of the two tails may explain differences in the results in fuel price elasticities between the U.S. and Europe, according to Gillingham and Munk-Nielsen. The Gillingham and Munk-Nielsen study finds a price responsiveness of driving of 30 percent for Denmark drivers but, if ample access to public transport is eliminated, this responsiveness changes to 13 percent. This is more in line with recent estimates from the U.S. for the fuel price responsiveness of driving.

In an additional study, Gillingham (2020) develops a rationale for the use of a 10 percent VMT rebound effect, and argues that the 20 percent used by the agencies in the most recent joint LDV rulemaking for the 2020–2026 GHG/fuel economy standards is too high.[31,32] Gillingham points out that the agencies argue that odometer reading data is the most reliable data when they are discussing the relationship between vehicle miles traveled and vehicle age, but do not make this distinction in the discussion of the VMT rebound effect. Gillingham argues that, when reviewing VMT rebound studies and attempting to develop a single value of a VMT rebound effect, studies based upon odometer readings should be given greater weight. This is because odometer reading data is more reliable, since it is measured rather than self-reported, and may be more representative of travel behavior by covering nearly the entire LDV fleet in a region.

Based upon a list of recent VMT studies that the agencies reviewed in the proposed 2022–2026 LDV standards, Gillingham presents a summary of literature relevant for his central estimate of the rebound effect of fuel economy standards in the U.S. He restricts his review to publicly available U.S.-based literature from the past decade. His review excludes estimates from outside of the U.S., in particular Europe, as travel behavior has been shown to be different due to a variety of factors including different urban forms and public transportation access. Second, Gillingham excludes some estimates from unpublished work that are inaccessible, or that estimate something other than the VMT rebound effect (i.e., response of gasoline demand to fuel price). Third, Gillingham excludes estimates that are inappropriate for using as an estimate of the rebound effect, based upon individual author’s judgements. For example, as mentioned above, Gillingham excludes his own study published in 2014, which examines the driving response to the 2008 gasoline price shock, an unusual period when gasoline prices were particularly salient to consumers.

According to Gillingham, a few clear findings are apparent. First, there is a relatively wide range of estimates. In general, studies using household survey data tend to have much higher rebound effect estimates than those using odometer reading data. Second, the average rebound effect over all studies that are considered by Gillingham is 14 percent, and the average over all studies using just odometer readings is 8 percent. According to Gillingham, based upon his review of relevant studies, he casts doubt on the argument for a central case estimate of 20 percent for the VMT rebound effect of U.S. LDV GHG/fuel economy standards.[33]

A study by the Dimitropoulos et al. (2018) presents a meta-analysis of 76 empirical studies and 1,138 estimates of elasticities of travel from 18 countries (i.e., the U.S., European countries, China and India) over the last fifty years, which can serve as possible measures of the VMT rebound effect.[34] Some of the most recent U.S. state-level studies using odometer readings data such as Knittel and Sandler (2018), Langer et al. (2017) and Wenzel and Fujita (2018) are not included in the meta-analysis. The meta-analysis uses an econometric approach to assess the sources of heterogeneity in rebound effect estimates across the studies. The overall world VMT rebound effect is estimated to be, on average, around 12 percent in the short-run, and roughly 32 percent in the long-run, across all of the studies considered. Other findings by Dimitropoulos et al. suggest that studies using household survey data typically produce long-run rebound estimates twice or more as large as studies based on aggregate data. The meta-analysis also finds that the VMT rebound effect is declining worldwide, at a rate of roughly 0.7 percentage points per year.

Dimitropoulos et al. provide VMT rebound estimates that vary by the price of gasoline, population density, and gross domestic product (GDP) per capita, based upon the meta-analysis results. They conclude that the VMT rebound effect increases with the price of gasoline and population density, and decreases with per capita GDP, making rebound estimates from different countries not directly comparable. Using 2018 U.S. values for gasoline price ($0.63/liter), population density (33.75/km2), and GDP per capita ($51,552) for the U.S., Dimitropoulos et al. results predict a long-run VMT rebound effect of roughly 20 percent for the U.S.[35]

In a Report entitled, "Science Advisory Board (SAB) Consideration of the Scientific and Technical Basis of the EPA's Proposed Rule titled *The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks*",[36] EPA's Scientific Advisory Board (SAB) provides comments on the VMT rebound estimate used in the proposed SAFE rule. On the magnitude of the 20 percent rebound value used, the SAB provides several recommendations. First, the SAB suggests that the Agency's consider several recent odometer-based VMT rebound studies (e.g., Langer et al. (2017); Knittel and Sandler (2018); and Wenzel and Fujita (2018))[26,27,30] which were not considered for the proposed SAFE rule. The SAB also recommends that the Agency not over-generalize on the importance of the rebound effect, assuming the implications of increased efficiency will be seen uniformly across sectors of the economy. Finally, the SAB recommends that the Agency consider the relative saturation of demand for VMT, the increasing role that the travel behaviors of Millennials, Baby Boomers and ride sharing services have in reducing the magnitude of the U.S. VMT rebound effect. In a concluding statement, the SAB comments, "Due to these concerns, the SAB recommends that the rebound estimate be reconsidered to account for the broader literature, and that it be determined through a full assessment of the quality and relevance of the individual studies rather than a simple average of results. A more in-depth analysis will allow the Agency to weight papers based on their quality and applicability: recent papers using strong methodology and U.S. data should be weighted more heavily than older papers, or those from outside the U.S., or those with weaker methodology."

3.1.4 Basis for Rebound Effect Used in this Final LDV Rule

EPA uses a single point estimate for the direct VMT rebound effect as an input to the agency's analyses for this final LDV GHG rule (2023–2026). Based on a review of estimates of the VMT rebound effect from recent analyses (i.e., since 2010) and some of the insights from VMT rebound studies completed before 2010, EPA is using a value of 10 percent for the direct rebound effect for this final rule. In Chapter 4.10, as sensitivities, EPA presents estimates of the impacts of using a five percent and 15 percent VMT rebound effect.

There is a wide variety of estimates of the VMT rebound effect from the recent analyses, in part, due to the many different methodologies and data sources used to try to quantify this impact. Given the broad range of values, EPA believes it is important to critically evaluate which studies are most likely to be reflective of the rebound effect that is relevant to the final standards (2023–2026). In other words, one cannot just take the "average" rebound estimates from literature to use for the VMT rebound effect for this final rule.

EPA applies the following critical factors when choosing a VMT rebound estimate for this final rulemaking:

1. **Geographic/Timespan relevance:** Priority is given to U.S., as opposed to international rebound studies, since U.S. studies are based upon U.S. LDV travel, land use patterns, and socio-economic conditions. U.S. national-level studies are most useful since they are based upon the geographic scale of this final rulemaking. Priority is given to studies that are based on U.S. demographic/land use patterns over timespans most relevant to this rulemaking's analytical timeframe (e.g., 2023–2050). Thus, we focus on studies relying upon time series data rather than single-year studies. Even well-executed single year studies have difficulty in controlling for confounding factors influencing the VMT rebound effect, so these studies are not given significant weight;

2. **Time period of study:** Priority is given to more recent rebound studies in the last decade, since their driving patterns are more likely to resemble driving patterns over the time frame of this final LDV rule;

3. **Reliability/Replicability of study:** Priority is given to studies that use measured odometer reading data for VMT. Many household survey studies rely on self-reported VMT data, which may not produce as reliable estimates of the VMT rebound effect as studies based on measured data. Also, odometer reading data is likely to more representative of travel behavior by covering nearly the entire LDV fleet in a region. Finally, the 2009 NHTS data was collected during the Great Recession time period. It is not clear how representative travel patterns in the U.S. were during this time period for developing estimates over timespans most relevant to this rulemaking's analytical timeframe (e.g., 2023–2050); and

4. **Strong statistical/methodological basis:** Priority is given to studies using strong statistical methods that effectively attempt to control and isolate the impacts of the VMT rebound effect.

The critical factors listed above are consistent with the SAB's recommendations on how to determine a preferred estimate of the magnitude of the VMT rebound effect for use in this final LDV GHG rule. EPA undertakes a comprehensive, overall, in-depth assessment of the full range of VMT rebound studies relevant for developing a preferred VMT rebound estimate for this final rule. EPA weighs the applicability and quality of each individual VMT rebound study in this overall assessment. EPA does not simply average the results of the relevant VMT studies in developing a VMT rebound estimate for this final rule. EPA gives more weight to U.S. rebound studies as opposed to international VMT rebound studies. In addition, EPA gives more weight to recent rebound studies (i.e., in the last decade). The application of the critical factors listed above to the relevant VMT rebound literature is presented below.

Studies that provide a U.S. estimate of the LDV VMT rebound effect are most applicable to estimating the overall VMT effects of the final LDV standards. The most recent national, U.S. studies are by Hymel and Small (2015), which estimates a rebound effect ranging from 4–18 percent, and Greene (2012), which concludes that the rebound effect "is by now on the order of 10 percent." Based upon the comments received on the proposal for this rule referencing Small's comments on the SAFE rule, EPA is using the 4 percent value from the Hymel and Small study (2015), and not the range. See Table 3-4 below. Since GHG standards result in improved vehicle efficiency, which lowers the cost of driving, and Hymel and Small found an asymmetric response to the costs of driving, the lower end of the range in the Hymel and Small estimates is more applicable for evaluating the final LDV GHG standards.

Both studies, Greene (2012) and Hymel and Small (2015), are based upon U.S. vehicle travel patterns, as opposed to relying on international (i.e., outside the U.S.) travel patterns. Both studies have been published in the last decade and are based upon the geographic scale of this final rulemaking – the national, U.S. level. Both studies estimate the VMT rebound effect looking at travel behavior over many years, as opposed to studies that rely on only a single year. As noted above, even well executed, single year studies may have difficulty in controlling for confounding factors influencing the VMT rebound effect. Both studies use solid statistical methods that are generally effective at isolating the impacts of the VMT rebound effect. See Table 3-4 below for the list of national, U.S. studies given significant weight in developing an estimate of the VMT rebound effect for this final rule.

The set of studies at the U.S. state-level using odometer readings further support the 10 percent VMT rebound estimate for the U.S. as a whole. These studies, for Pennsylvania: Gillingham et al. (2015); for California: Gillingham (2011)/Knittel and Sandler (2018); for Ohio: Langer et al. (2017); and for Texas: Wenzel and Fujita (2018), find VMT rebound effects of 10, 1, 13, 12, and 9–16 percent, respectively. See Table 3-4 below for the list of U.S. state-level, odometer studies given significant weight in developing an estimate of the VMT rebound effect for this final rule.

Table 3-4: Studies Given Significant Weight in Developing an Estimate of the VMT Rebound Effect for this Final Rule

Author	Year	Estimate of Rebound Effect	Description/ Time Period
U.S. National			
Greene	2012	10%	Aggregate 1966-2007
Hymel and Small	2015	4%	State-level 2000-2009
State-Level Odometer			
Gillingham	2011	1%	California 2001-2009
Gillingham et al.	2015	10%	Pennsylvania 2000-2010
Langer et al.	2017	12%	Ohio 2009-2013
Wenzel and Fujita	2018	9-16%	Texas 2005-2010
Knittel and Sandler	2018	13%	California 1998-2010

All of the state-level studies are based upon U.S. vehicle travel patterns, as opposed to relying on international (i.e., outside the U.S.) travel patterns. All five of the studies have been published in the past decade. These state-level studies use odometer readings to measure VMT, as opposed to self-reported data, which provides more confidence in the reliability of their results. In addition, odometer reading data is likely to be more representative of travel behavior by covering nearly the entire LDV fleet in a region. Also, these studies all use time series, rather than single year, data to estimate the VMT rebound effect, avoiding possible confounding effects of using a single year's data. All of the U.S. state-level studies use solid statistical methods that are generally effective at isolating the impacts of the VMT rebound effect. The Gillingham (2014) study, which found a 22 percent VMT rebound effect in California, is excluded from consideration in the set of state-level rebound studies using odometer data. As Gillingham points out, this study assesses the response to driving from a salient 2008 gasoline price shock, which is quite different than gradual changes in fuel economy from the final LDV standards.

The four states considered in the studies – Pennsylvania, Ohio, Texas and California – are geographically diverse, with different population sizes, incomes, demographic characteristics, and vehicle fleet characteristics. Nevertheless, these studies provide estimates of VMT rebound effects that are roughly clustered in the 10 percent range. Thus, these U.S. state-level studies, based on odometer readings, provide support for the use of a 10 percent rebound effect in developing a single VMT rebound estimate for the U.S. nation as a whole.

The West et al. study (2017) on the CARS (Cash for Clunkers) program did not find a VMT rebound effect (i.e., a VMT rebound effect of zero). This study uses odometer data from the state of Texas. But the VMT response to a vehicle scrappage program could be very different than for a program that results in a gradual increase in fuel economy over time, such as the LDV final rule considered here. For example, West et al. find that vehicle attribute changes (i.e., lower curb weight/horsepower) offset the lower costs of driving, resulting in a zero-rebound effect. It is not clear how vehicle attributes will change with this final LDV rule. Therefore, little to no weight is given to the West et al. study in determining a VMT rebound effect for this final rule.

Su (2012), Liu et al. (2014), Leung (2015) and Linn (2016), each using NHTS 2009 data, find rebound effects that vary from 10–40 percent. Wang and Chen (2014), using the 2009 NHTS data as well, find a rebound effect only for low-income households. These widely different results based upon the same dataset suggest that these studies may not provide reliable estimates of the VMT rebound effect. The concern is that different methodological approaches with the same set of data yield different results. All of the household survey studies are based on self-reported VMT data, suggesting that the results may not be as reliable as studies based on odometer readings. Further, the NHTS data are for a single year. Even well executed studies based upon a single year of data may have difficulty controlling for confounding factors influencing estimates of the VMT rebound effect. Also, travel and household data from the 2009 NHTS was collected while the U.S. was in the midst of the Great Recession. The Great Recession led to significant employment and output losses in the U.S., which may have possibly led to unusual travel patterns.

This final rule uses AEO 2021 as the basis for projecting economic and fuel market trends during time frame of analysis of this final rule.[37] The AEO 2021 projects that U.S. Gross Domestic Product will increase over time. Some of the national, aggregate studies of the U.S., Hymel and Small (2015) and Greene (2012), find that the VMT rebound effect decreases as household incomes rise. As incomes rise, the value of time spent driving is typically assumed to rise as well. Thus, the time cost of travel becomes a larger fraction of total travel costs, so vehicle use may become less responsive to variations in fuel costs. Wang and Chen find that only low-income households have a rebound effect, which is consistent with the VMT rebound effect diminishing with increases in income. On the other hand, Gillingham, (2014) finds that the VMT rebound effect increases with household income. But the Gillingham (2014) study examines the travel response to a salient gasoline price increase, which is somewhat different than a gradual improvement in fuel economy from this final LDV rule. Also, De Borger et al. (2016) did not find a significant impact of income on the VMT rebound effect. Thus, the evidence of how the rebound effect varies with income is somewhat mixed. While the relationship between the VMT rebound effect and income is supported by some of the national, aggregate studies; some, but less, weight is given to this factor in determining a VMT rebound value for this final rule.

In summary, the 10 percent VMT rebound value chosen for use in these final LDV GHG standards (2023–2026) is based upon applying a set of critical factors – geographic/timespan relevance, time period, repeatability/reliability, and statistical/methodological basis – and the weight of evidence from multiple recent studies (i.e., studies since 2010), based upon an updated and rigorous review of the large body of literature on this topic. A combination of the recent U.S., national VMT rebound studies and recent, odometer-based, VMT rebound studies for different states – Pennsylvania, Ohio, Texas and California – that are geographically diverse, with different population sizes, incomes, demographic characteristics, and vehicle fleet characteristics, support a single point value of 10 percent for the direct VMT rebound effect. All of the studies estimate the VMT rebound effect over many years, as opposed to a single year, and use strong statistical methods. A simple average of all seven studies listed in Table 3-4 of this final rule results in a VMT rebound value of 8.9 percent. A simple average of all of the state-level, odometer-based VMT rebound studies listed in Table 3-4 results in a VMT rebound estimate of 9.7 percent. The four most recent state-level, odometer-based VMT rebound studies since 2015 (i.e., Gillingham et al., Langer et al., Wenzel and Fujita and Knittel and Sandler) have a simple average VMT rebound estimate of 11.9 percent. A variety of factors discussed in this rulemaking could potentially lower the VMT rebound effect estimate, including: using salient fuel prices to represent the gradual cost of driving from GHG standards; asymmetric driver responses to fuel prices/costs of driving; the impacts of increases in income on the VMT rebound effect; and, the VMT rebound effect with high fuel efficient vehicles. More research is needed on these factors, particularly using odometer-based data, before the impacts of these factors can more significantly influence the overall VMT rebound estimate being used in this rule. To conclude, we believe that EPA's evaluation of the recent, U.S. VMT rebound literature provides a very reliable estimate of the VMT rebound effect, 10 percent, and we have used this value within this LDV GHG final rule.

3.2 Energy Security Impacts

This final rule is designed to require improvements in the fuel economy of light-duty vehicles (LDV) and thereby reduce fuel consumption and GHG emissions. In turn, this final rule helps to reduce U.S. petroleum imports. A reduction of U.S. petroleum imports reduces both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S., thus increasing U.S. energy security. In other words, reduced U.S. oil imports act as a "shock absorber" when there is a supply disruption in world oil markets. This section summarizes the agency's estimates of U.S. oil import reductions and energy security benefits of the final light-duty GHG standards for model years 2023–2026.

Energy independence and energy security are distinct but related concepts, and an analysis of energy independence informs our analysis of energy security.[38] The goal of U.S. energy independence is the elimination of all U.S. imports of petroleum and other foreign sources of energy.[39] U.S. energy security is broadly defined as the continued availability of energy sources at an acceptable price.[40] Most discussions of U.S. energy security revolve around the topic of the economic costs of U.S. dependence on oil imports.[i,41] We note that energy independence associated with oil is theoretically achievable (i.e. the U.S. produces all of its own oil). On the other hand, energy security risks can never be completely eliminated because the price of energy consumed (i.e., oil) in the U.S. is affected by global commodity markets.

The U.S.'s oil consumption has been gradually increasing in recent years (2015-2019) before dropping dramatically as a result of the COVID pandemic in 2020.[42] The U.S. has increased its production of oil, particularly "tight" (i.e., shale) oil, over the last decade.[43] As a result of the recent increase in U.S. oil production, the U.S. became a net exporter of crude oil and product in 2020 and is now projected to be a net exporter of crude oil and product through 2023 to 2050, the time frame of this analysis.[44] This is a significant reversal of the U.S.'s net export position since the U.S. has been a substantial net importer of crude oil and product starting in the early 1950s.[45]

Given that the U.S. is projected to be a net exporter of crude oil and product for the foreseeable future, one could reason that the U.S. does not have a significant energy security problem anymore. However, U.S. refineries still rely on significant imports of heavy crude oil

[i] The issue of cyberattacks is another energy security issue that could grow in significance over time. For example, one of the U.S.'s largest pipeline operators, Colonial Pipeline, was forced to shut down after being hit by a ransomware attack. The pipeline carries refined gasoline and jet fuel from Texas to New York.

from potentially unstable regions of the world. Also, oil exporters with a large share of global production have the ability to raise or lower the price of oil by exerting the market power associated with the Organization of Petroleum Exporting Countries (OPEC) to alter oil supply relative to demand. These factors contribute to the vulnerability of the U.S. economy to episodic oil supply shocks and price spikes, even when the U.S. is projected to be an overall net exporter of crude oil and product.

3.2.1 Review of Historical Energy Security Literature

Energy security discussions are typically based around the concept of the oil import premium. The oil import premium is the extra cost of importing oil beyond the price of the oil itself as a result of: (1) potential macro-economic disruption and increased oil import costs to the economy from oil price spikes or "shocks" and (2) monopsony impacts. Monopsony impacts stem from changes in the demand for imported oil, which changes the price of all imported oil.

The so called oil import premium gained attention as a guiding concept for energy policy in the aftermath around of the oil shocks of the 1970's (Bohi and Montgomery 1982, EMF 1982).[46] Plummer (1982) provided valuable discussion of many of the key issues related to the oil import premium as well as the analogous oil stockpiling premium.[47] Bohi and Montgomery (1982) detailed the theoretical foundations of the oil import premium and established many of the critical analytic relationships.[48] Hogan (1981) and Broadman and Hogan (1986, 1988) revised and extended the established analytical framework to estimate optimal oil import premia with a more detailed accounting of macroeconomic effects.[49,50] Since the original work on energy security was undertaken in the 1980's, there have been several reviews on this topic by Leiby, Jones, Curlee and Lee (1997) and Parry and Darmstadter (2004).[51,52]

The economics literature on whether oil shocks are the same level of threat to economic stability as they once were, is mixed. Some of the literature asserts that the macroeconomic component of the energy security externality is small. For example, the National Research Council (2009) argued that the non-environmental externalities associated with dependence on foreign oil are small, and potentially trivial.[53] Analyses by Nordhaus (2007) and Blanchard and Gali (2010) questioned the impact of oil price shocks on the economy in the early 2000 time frame.[54] They were motivated by attempts to explain why the economy actually expanded during the oil shock in the early 2000 time frame, and why there was no evidence of higher energy prices being passed on through higher wage inflation. One reason, according to Nordhaus and Blanchard and Gali, is that monetary policy has become more accommodating to the price impacts of oil shocks. Another reason is that consumers have simply decided that such movements are temporary and have noted that price impacts are not passed on as inflation in other parts of the economy.

Hamilton (2012) reviewed the empirical literature on oil shocks and suggested that the results are mixed, noting that some work (e.g. Rasmussen and Roitman (2011)) finds less evidence for economic effects of oil shocks or declining effects of shocks (Blanchard and Gali (2010)), while other work continues to find evidence regarding the economic importance of oil shocks.[55] For example, Baumeister and Peersman (2011) find that an "oil price increase of a given size seems to have a decreasing effect over time, but noted that the declining price-elasticity of demand means that a given physical disruption had a bigger effect on price and turned out to have a similar effect on output as in the earlier data".[56] Hamilton observed that "a negative effect of oil prices on real output has also been reported for a number of other countries, particularly when nonlinear functional forms have been employed" (citing as examples Kim (2012), Engemann, Kliesen, and Owyang (2011)).[57,58] Alternatively, rather than a declining effect, Ramey and Vine (2010) find "remarkable stability in the response of aggregate real variables to oil shocks once we account for the extra costs imposed on the economy in the 1970s by price controls and a complex system of entitlements that led to some rationing and shortages."[59]

Some of the literature on oil price shocks emphasizes that economic impacts depend on the nature of the oil shock, with differences between price increases caused by a sudden supply loss and those caused by rapidly growing demand. Recent analyses of oil price shocks have confirmed that "demand-driven" oil price shocks have greater effects on oil prices and tend to have positive effects on the economy while "supply-driven" oil shocks still have negative economic impacts (Baumeister, Peersman and Robays (2010)).[60] A paper by Kilian and Vigfusson (2014), for example, assigned a more prominent role to the effects of price increases that are unusual, in the sense of being beyond the range of recent experience.[61] Kilian and Vigfussen also concluded that the difference in response to oil shocks may well stem from the different effects of demand- and supply-based price increases: "One explanation is that oil price shocks are associated with a range of oil demand and oil supply shocks, some of which stimulate the U.S. economy in the short-run and some of which slow down U.S. growth (see Kilian 2009a)".[62]

The general conclusion that oil supply-driven shocks reduce economic output is also reached in a paper by Cashin et al. (2014) which focused on 38 countries from 1979–2011.[63] They stated: "The results indicate that the economic consequences of a supply-driven oil-price shock are very different from those of an oil-demand shock driven by global economic activity, and vary for oil-importing countries compared to energy exporters". Cashin et al. continues "oil importers (including the U.S.) typically face a long-lived fall in economic activity in response to a supply-driven surge in oil prices". But almost all countries see an increase in real output for an oil-demand disturbance.

EPA's assessment of the energy security literature finds that there are benefits to the U.S. from reductions in oil imports. But there is some debate as to the magnitude, and even the existence, of energy security benefits from U.S. oil import reductions. Over the last decade, differences in economic impacts from oil demand and oil supply shocks have been distinguished. The oil security premium calculations in this analysis are based on price shocks from potential future supply events only. Oil supply shocks, which reduce economic activity, have been the predominant focus of oil security issues since the oil price shocks/oil embargoes of the 1970's.

3.2.2 Review of Recent Energy Security Literature

There have also been a handful of more recent studies undertaken in the last few years that are relevant for the issue of energy security: one by Resources for the Future (RFF), a study by Brown, two studies by Oak Ridge National Laboratory (ORNL), and a couple of studies, Newell and Prest and Bjornland et al., on the responsiveness of U.S. tight oil (i.e., shale oil) to world oil price changes. We provide a brief review and high-level summary of each of these studies below.

The RFF study (2017) attempts to develop updated estimates of the relationship among gross domestic product (GDP), oil supply and oil price shocks, and world oil demand and supply elasticities.[64] In a follow-on study, Brown summarized the RFF study results well.[65] The RFF work argues that there have been major changes that have occurred in recent years which have reduced the impacts of oil shocks on the U.S. economy. First, the U.S. is less dependent on imported oil than in the early 2000s due in part to the “fracking revolution” (i.e., tight/shale oil), and to a lesser extent, increased production of renewable fuels. In addition, RFF argues that the U.S. economy is more resilient to oil shocks than in the earlier 2000 time frame. Some of the factors that make the U.S. more resilient to oil shocks include increased global financial integration and greater flexibility of the U.S. economy (especially labor and financial markets), many of the same factors that Nordhaus and Blanchard and Gali pointed to as discussed above.

In the RFF effort, a number of comparative modeling scenarios are conducted by several economic modeling teams using three different types of energy-economic models to examine the impacts of oil shocks on U.S. GDP. The first is a dynamic stochastic general equilibrium model developed by Balke and Brown.[66] The second set of modeling frameworks use alternative structural vector autoregressive models of the global crude oil market.[67,68,69] The last of the models utilized is the National Energy Modeling System (NEMS).[70]

Two key parameters are focused upon to estimate the impacts of oil shock simulations on U.S. GDP: oil price responsiveness (i.e., the short-run price elasticity of demand for oil) and GDP sensitivity (i.e., the elasticity of GDP to an oil price shock). The more inelastic (i.e., the less responsive) short-run oil demand is to changes in the price of oil, the higher will be the price impacts of a future oil shock. Higher price impacts from an oil shock result in higher GDP losses. The more inelastic (i.e., less sensitive) GDP is to an oil price change, the less the loss of U.S. GDP with future oil price shocks.

For oil price responsiveness, RFF reports three different values: a short-run price elasticity of oil demand from their assessment of the “new literature”, -0.17; a “blended” elasticity estimate; -0.05, and short-run oil price elasticities from the “new models” RFF uses, ranging from -0.20 to -0.35. The “blended” elasticity is characterized by RFF in the following way: “Recognizing that these two sets of literature [old and new] represent an evolution in thinking and modeling, but that the older literature has not been wholly overtaken by the new, Benchmark-E [the blended elasticity] allows for a range of estimates to better capture the uncertainty involved in calculating the oil security premiums.”

The second parameter that RFF examines is the GDP sensitivity. For this parameter, RFF’s assessment of the “new literature” finds a value of -0.018, a “blended elasticity” estimate of -0.028, and a range of GDP elasticities from the “new models” that RFF uses that range from -0.007 to -0.027. One of the limitations of the RFF study is that the large variations in oil price over the last fifteen years are believed to be predominantly “demand shocks”: for example, a rapid growth in global oil demand followed by the Great Recession and then the post-recession recovery.

The only supply-side oil shock in the last several years was the attack on the Saudi Aramco Abqaiq oil processing facility and the Khurais oil field (which took place after the publication of RFF’s study). On September 14th, 2019, a drone and cruise missile attack damaged the Saudi Aramco Abqaiq oil processing facility and the Khurais oil field in eastern Saudi Arabia. The Abqaiq oil processing facility is the largest crude oil processing and stabilization plant in the world, with a capacity of roughly 7 MMBD or roughly seven percent of global crude oil production capacity.[71] On September 16th, the first full day of commodity trading after the attack, both Brent and West Texas Intermediate (WTI) crude oil prices surged by $7.17/barrel and $8.34/barrel, respectively, in response to the attack, the largest price increase in roughly a decade.

However, by September 17th, Saudi Aramco reported that the Abqaiq plant was producing 2 MMBD, and they expected its entire output capacity to be fully restored by the end of September.[72] Tanker loading estimates from third-party data sources indicated that loadings at two Saudi Arabian export facilities were restored to the pre-attack levels.[73] As a result, both Brent and WTI crude oil prices fell on September 17th, but not back to their original levels. The oil price spike from the attack on the Abqaiq plant and Khurais oil field was prominent and unusual, as Kilian and Vigfusson (2014) describe. While pointing to possible risks to world oil supply, the oil price shock was short-lived, and generally viewed by market participants as being transitory, so it did not influence oil markets over a sustained time period. Thus, there is little recent empirical evidence to estimate the response of the U.S. economy to an oil supply shock of a significant magnitude.[j]

A second set of recent studies related to energy security are from ORNL. In the first study, ORNL (2018) undertakes a quantitative meta-analysis of world oil demand elasticities based upon the recent economics literature.[74] The ORNL study estimates oil demand elasticities for two sectors (transportation and non-transportation) and by world regions (OECD and Non-OECD) by meta-regression. To establish the dataset for the meta-analysis, ORNL undertakes a literature search of peer reviewed journal articles and working papers between 2000 and 2015 that contain estimates of oil demand elasticities. The dataset consisted of 1,983 observations from 75 published studies. The study finds a weighted short-run price elasticity of world oil demand of -0.07 and a long-run price elasticity of world oil demand of -0.26.

The second relevant ORNL (2018) study from the standpoint of energy security is a meta-analysis that examines the impacts of oil price shocks on the U.S. economy as well as many other net oil-importing economies.[75] Nineteen studies after the year 2000 were identified that contain quantitative/accessible estimates of the economic impacts of oil price shocks. Almost all studies included in the review were published since 2008. The key result that the study finds is a short-run oil price elasticity of U.S. GDP, roughly one year after an oil shock, of -0.021, with a 68 percent confidence interval of -0.006 to -0.036.

Only in recent years have the implications of the “tight oil revolution” been felt in the international oil market where U.S. production of oil is rising to be roughly on par with Saudi Arabia and Russia. Recent economics literature of the tight (i.e., shale/unconventional) oil expansion in the U.S. has a bearing on the issue of energy security as well. It could be that the large expansion in shale oil has eroded the ability of OPEC to set world oil prices to some degree, since OPEC cannot directly influence shale oil production decisions. Also, the growth in U.S. oil supply is reducing the share of global oil supply controlled by OPEC, also possibly limiting OPEC's degree of market power. But given that the shale oil expansion is a relatively

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[j] The Hurricanes Katrina/Rita in 2005 primarily caused a disruption in U.S. oil refinery production, with a more limited disruption of some crude supply in the U.S. Gulf Coast area. Thus, the loss of petroleum product exceeded the loss of crude oil, and the regional impact varied even within the U.S. The Katrina/Rita Hurricanes were a different type of oil disruption event than is quantified in the Stanford EMF risk analysis framework, which provides the oil disruption probabilities than ORNL is using.

recent trend, it is difficult to know how much of an impact the increase in shale oil is having, or will have, on OPEC behavior.

Two recent studies have examined the characteristics of tight oil supply that have relevance for the topic of energy security. In the context of energy security, the question that arises is: can tight oil respond to an oil price shock more quickly and substantially than conventional oil?[76] If so, then tight oil could potentially lessen the impacts of future oil shocks on the U.S. economy by moderating the price increases from a future oil supply shock.

Newell and Prest (2019) look at differences in the price responsiveness for oil wells, using a detailed dataset of 164,000 oil wells, during the time frame of 2000–2015 in five major oil-producing states: Texas, North Dakota, California, Oklahoma, and Colorado.[77] They find that unconventional oil wells are more price responsive than conventional oil wells, mostly due to their much higher productivity, but the estimated price elasticity is still small. Newell and Prest also estimate a medium-run price elasticity of oil supply of 0.12. Newell and Prest note that the shale oil supply response still takes more time to arise than is typically considered for a "swing producer", referring to a supplier able to increase production quickly, within 30 to 90 days. In the past, only Saudi Arabia and possibly one or two other oil producers in the Middle East, have been able to ramp up oil production in a short period of time. From the standpoint of energy security, the most relevant time frame of analysis is roughly a year, considered the short-run responsiveness of oil demand to price.

Another study, by Bjornland et al. (2021), uses a well-level monthly production data set covering more than 15,000 crude oil wells in North Dakota to examine differences in supply responses between conventional and tight oil/shale oil.[78] They find a short-run (i.e., one-month) supply elasticity with respect to oil price for tight oil wells of 0.076, whereas the one-month response of conventional oil supply was not statistically different from zero. Both the results from the Newell and Prest and Bjornland et al. suggest that tight oil may have a larger supply response to oil prices in the short-run than conventional oil, although the estimated short-run elasticity is still small.

Finally, despite continuing uncertainty about oil market behavior and outcomes and the sensitivity of the U.S. economy to oil shocks, it is generally agreed that it is beneficial to reduce petroleum fuel consumption from an energy security standpoint. U.S. oil markets are expected to remain tightly linked to trends in the world crude oil market. It is not just U.S. crude oil imports alone, but both imports and consumption of petroleum from all sources and their role in economic activity, that exposes the U.S. to risk from price shocks in the world oil price. The relative significance of petroleum consumption and import levels for the macroeconomic disturbances that follow from oil price shocks is not fully understood. Recognizing that changing petroleum consumption will change U.S. imports, this assessment of oil costs focuses on those incremental social costs that follow from the resulting changes in net imports, employing the usual oil import premium measure.

3.2.3 Cost of Existing U.S. Energy Security Policies

An additional often-identified component of the full economic costs of U.S. oil imports is the costs to the U.S. taxpayers of existing U.S. energy security policies. The two primary examples are maintaining the Strategic Petroleum Reserve (SPR) and maintaining a military presence to help secure a stable oil supply from potentially vulnerable regions of the world.

The SPR is the largest stockpile of government-owned emergency crude oil in the world. Established in the aftermath of the 1973/1974 oil embargo, the SPR provides the U.S. with a response option should a disruption in commercial oil supplies threaten the U.S. economy. While the costs for building and maintaining the SPR are more clearly related to U.S. oil use and imports, historically these costs have not varied in response to changes in U.S. oil import levels. Thus, while the effect of the SPR in moderating price shocks is factored into the analysis that EPA is using to estimate the macroeconomic oil security premiums, the cost of maintaining the SPR is excluded.

EPA also has considered the possibility of quantifying the military benefits components of energy security but has not done so here for several reasons. The literature on the military components of energy security has described four broad categories of oil-related military and national security costs, all of which are hard to quantify. These include possible costs of U.S. military programs to secure oil supplies from unstable regions of the world, the energy security costs associated with the U.S. military's reliance on petroleum to fuel its operations, possible national security costs associated with expanded oil revenues to "rogue states" and relatedly the foreign policy costs of oil insecurity.

Of these categories listed above, the one that is most clearly connected to petroleum use and is, in principle, quantifiable is the first: the cost of military programs to secure oil supplies and stabilize oil supplying regions. There is an ongoing literature on the measurement of this component of energy security, but methodological and measurement issues – attribution and incremental analysis – pose two significant challenges to providing a robust estimate of this component of energy security. The attribution challenge is to determine which military programs and expenditures can properly be attributed to oil supply protection, rather than some other objective. The incremental analysis challenge is to estimate how much the petroleum supply protection costs might vary if U.S. oil use were to be reduced or eliminated. Methods to address both of these challenges are necessary for estimating the effect on military costs arising from a modest reduction (not elimination) in oil use attributable to this final rule.

Since "military forces are, to a great extent, multipurpose and fungible" across theaters and missions (Crane et al. 2009), and because the military budget is presented along regional accounts rather than by mission, the allocation to particular missions is not always clear.[79] Approaches taken usually either allocate "partial" military costs directly associated with operations in a particular region, or allocate a share of total military costs (including some that are indirect in the sense of supporting military activities overall) (Koplow and Martin 1998).[80] The challenges of attribution and incremental analysis have led some to conclude that the mission of oil supply protection cannot be clearly separated from others, and the military cost component of oil security should be taken as near zero (Moore et al. 1997).[81]

Stern (2010), on the other hand, argues that many of the other policy concerns in the Persian Gulf follow from oil, and the reaction to U.S. policies taken to protect oil.[82] Stern presents an estimate of military cost for Persian Gulf force projection, addressing the challenge of cost allocation with an activity-based cost method. He uses information on actual naval force deployments rather than budgets, focusing on the costs of carrier deployment. As a result of this different data set and assumptions regarding allocation, the estimated costs are much higher, roughly 4 to 10 times, than other estimates. Stern also provides some insight on the analysis of incremental effects, by estimating that Persian Gulf force projection costs are relatively strongly correlated to Persian Gulf petroleum export values and volumes. Still, the issue remains of the marginality of these costs with respect to Persian Gulf oil supply levels, the level of U.S. oil imports, or U.S. oil consumption levels.

Delucchi and Murphy (2008) seek to deduct from the cost of Persian Gulf military programs the costs associated with defending U.S. interests other than the objective of providing more stable oil supply and price to the U.S. economy.[83] Excluding an estimate of cost for missions unrelated to oil, and for the protection of oil in the interest of other countries, Delucchi and Murphy estimated military costs for all U.S. domestic oil interests of between $24 and $74 billion annually. Delucchi and Murphy assume that military costs from oil import reductions can be scaled proportionally, attempting to address the incremental issue.

Crane et al. considers force reductions and cost savings that could be achieved if oil security were no longer a consideration. Taking two approaches and guided by post-Cold War force draw downs and by a top-down look at the current U.S. allocation of defense resources, they concluded that $75–$91 billion, or 12–15 percent of the current U.S. defense budget, could be reduced.

Finally, an Issue Brief by Securing America's Future Energy (SAFE) (2018) found a conservative estimate of approximately $81 billion per year spent by the U.S. military protecting global oil supplies.[84] This is approximately 16 percent of the recent U.S. Department of Defense's budget. Spread out over the 19.8 million barrels of oil consumed daily in the U.S. in 2017, SAFE concludes that the implicit subsidy for all petroleum consumers is approximately $11.25 per barrel of crude oil, or $0.28 per gallon. According to SAFE, a more comprehensive estimate suggests the costs could be greater than $30 per barrel, or over $0.70 per gallon.[85]

As in the examples above, an incremental analysis can estimate how military costs would vary if the oil security mission is no longer needed, and many studies stop at this point. It is substantially more difficult to estimate how military costs would vary if U.S. oil use or imports are partially reduced, as is projected to be a consequence of this final rule. Partial reduction of U.S. oil use surely diminishes the magnitude of the security problem, but there is uncertainty that supply protection forces and their costs could be scaled down in proportion, and there remains the associated goal of protecting supply and transit for U.S. allies and other importing countries, if they do not decrease their petroleum use as well.[86] While military costs are an important consideration, EPA continues to be unaware of a robust methodology for assessing the effect on military costs of a partial reduction in U.S. oil use and imports. Therefore, we do not include military cost impacts in EPA's benefit and cost analysis for this final rule.

3.2.4 U.S. Oil Import Reductions from this Final Rule

Over the time frame of analysis for this final rule, 2023–2050, the U.S. Department of Energy's (DOE) Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2021 (Reference Case) projects that the U.S. will be both an exporter and an importer of crude oil.[87] The U.S. produces more light crude oil than its refineries can refine. Thus, the U.S. exports lighter crude oil and imports heavier crude oils to satisfy the needs of U.S. refineries, which are configured to efficiently refine heavy crude oil. U.S. crude oil exports are projected to be gradually increasing from 3 million barrels per day (MMBD) in 2023 to 3.5 MMBD in 2026 and remain above 3 MMBD through 2050. U.S. crude oil imports, meanwhile, are projected to decline modestly from 7.8 MMBD in 2023 to 7.5 MMBD in 2026. U.S. crude oil imports continue to decrease modestly to 6.9 MMBD by 2030, before rising to the 7.6 MMBD in 2050.

The AEO 2021 projects that U.S. net oil product exports will be 5.3 MMBD in 2023 and rise modestly to 5.6 MMBD in 2026. After 2026, U.S. net oil product exports are projected to be somewhat greater than five MMBD until 2045, before decreasing modestly to 4.6 MMBD in 2050. Given the pattern of U.S. crude oil exports/imports, and U.S. net oil product exports, the U.S. is projected to be a net petroleum (crude oil and product) exporter from 2023 through 2050. For example, from 2023 to 2026, the U.S. net crude oil and product exports increase steadily from 0.5 to 1.6 MMBD. U.S. net crude oil and product exports increase to roughly 2 MMBD in the 2030 to 2035 time frame, before tapering off to 0.1 MMBD by 2050.

Since the U.S. is projected to continue importing significant quantities of crude oil through 2050, EPA's assessment is that the U.S. it is not expected to achieve the overall goal of U.S. energy independence during the analytical time frame of this rule. However, the U.S. is projected to be a net exporter of crude oil and products through 2050.

U.S. oil consumption is projected to be fairly steady for the time period from 2023 to 2050. From 2023 to 2040, projected U.S. oil consumption is fairly constant at roughly 20 MMBD before increasing modestly to roughly 21 MMBD in the 2045–2050 time period. During the 2023–2050 time frame, the AEO projects that the U.S. will continue to consume significant quantities of oil and will likewise continue to rely on significant quantities of crude oil imports.

Estimated fuel consumption changes from this final GHG rule are presented in Chapter 5.2. Based on a detailed analysis of differences in U.S. fuel consumption, crude oil imports/exports and exports of petroleum products for the time frame 2023–2050, and using the AEO 2021 (Reference Case) and two alternative sensitivity cases, i.e., (Low Economic Growth) and (High Economic Growth), EPA estimates that approximately 91 percent of the change in fuel consumption resulting from the final LDV GHG standards is likely to be reflected in reduced U.S. imports of crude oil.[k] The 91 percent oil import factor is calculated by taking the ratio of the changes in U.S. net crude oil and product imports divided by the change in U.S. oil consumption in the different AEO cases. Thus, on balance, each gallon of petroleum reduced as a result of the final LDV GHG Rule is anticipated to reduce total U.S. imports of petroleum by 0.91 gallons.

Based upon the changes in fuel consumption estimated in Chapter 5.2 and the 91 percent oil import reduction factor, the reduction in U.S. oil imports as a result of the final LDV GHG standards are estimated in Table 3-5 below for the 2023–2050 time frame. For comparison purposes, based upon the AEO 2021 (Reference Case), Table 3-5 also shows the U.S.'s projected crude oil exports and imports, net oil product exports, net crude oil/product exports and U.S. oil consumption for the years 2023–2050.[88]

k We looked at changes in U.S. crude oil imports/exports and net petroleum products in the AEO 2021 Reference Case, Table 11. Petroleum and Other Liquids Supply and Disposition, in comparison to two alternative cases from the AEO 2021. See the spreadsheet, "AEO2021 Change in oil product demand on imports".

Table 3-5: Projected Trends in U.S. Oil Exports/Imports, Net Oil Product Exports, Net Crude Oil/Product Exports, Oil Consumption and U.S. Oil Import Reductions Resulting from the Final LDV GHG rule from 2023 to 2050 (Millions of barrels per day (MMBD))*

Year	U.S. Crude Oil Exports	U.S. Crude Oil Imports	U.S. Net Oil Product Exports	U.S. Net Crude Oil and Product Exports	U.S. Oil Consumption	U.S. Oil Import Reductions from Final Rule*
2023	3.0	7.8	5.3	0.5	20.0	0.0
2024	3.4	7.8	5.4	0.9	20.1	0.1
2025	3.3	7.5	5.6	1.4	20.2	0.1
2026	3.5	7.5	5.6	1.6	20.2	0.2
2030	3.1	6.9	5.9	2.0	20.2	0.4
2035	3.3	7.0	5.6	1.9	20.4	0.7
2040	3.2	7.5	5.5	1.2	20.6	0.8
2045	3.1	7.3	5.1	1.0	21.0	0.9
2050	3.1	7.6	4.6	0.1	21.6	0.9
* Chapter 5.2 presents the total barrels of oil reduced due to the final standards. Here we present the barrels of imported oil reduced (per day). The values shown here account for the estimated oil import reduction as percent of total oil demand reduction (91 percent) and divides by 365 days in a year.						

3.2.5 Oil Security Premiums Used for this Final Rule

In order to understand the energy security implications of reducing U.S. oil imports, EPA has worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the social costs and energy security implications of oil use. The energy security estimates provided below are based upon a methodology developed in a peer-reviewed study entitled, "The Energy Security Benefits of Reduced Oil Use, 2006-2015," completed in 2008.[89] This ORNL study is an updated version of the approach used for estimating the energy security benefits of U.S. oil import reductions developed in a 1997 ORNL Report.[90] This approach has been used to estimate energy security benefits for the LDV GHG and fuel economy standards (2012–2016)/(2017–2025) and the HDV GHG/fuel economy standards Phase I (2014–2018) and Phase II (2018 and later).[91,92,93]

When conducting this analysis, ORNL considers the full cost of importing petroleum into the U.S. The full economic cost (i.e., labeled oil security premiums below) is defined to include two components in addition to the purchase price of petroleum itself. These are: (1) the higher costs/benefits for oil imports resulting from the effect of U.S. demand on the world oil price (i.e., the "demand" or "monopsony" costs/benefits); and (2) the risk of reductions in U.S. economic output and disruption to the U.S. economy caused by sudden disruptions in the supply of imported oil to the U.S. (i.e., the avoided macroeconomic disruption/adjustment costs).

For this final LDV GHG rule, EPA is using updated oil security premium values estimated using ORNL's methodology, which incorporates the oil price projections and energy market and economic trends, particularly regional oil supplies and demands at a global level (i.e., U.S./OPEC/rest of the world), from the AEO 2021 into its model. For the proposed LDV GHG rule, we used the AEO 2018 for estimating the oil security premiums. The macroeconomic oil security premium values in this final LDV rule, based on AEO 2021 data, are 10–15 percent lower than the ones in the proposed LDV rule using AEO 2018. The smaller values result from lower projections of U.S. crude oil net import levels and U.S. crude oil import prices in AEO 2021 relative to AEO 2018. The projected 2023–2026 average oil import cost for the U.S. is 28 percent lower in the AEO 2021 than the AEO 2018 (19 percent lower for 2023–2050) and the projected AEO 2021 U.S. net crude oil imports are also 28 percent lower, on average, for 2023–2026, than in AEO 2018 (28 percent lower as well for 2023–2050).

EPA only considers the avoided macroeconomic disruption/adjustment costs oil security premiums (i.e., labeled macroeconomic oil security premiums below), since the monopsony impacts of this final rule are considered transfer payments. In previous LDV GHG rules when the U.S. was forecasted by the U.S. Energy Information Administration (EIA) to be a net importer of crude oil and product, monopsony impacts represented reduced payments by U.S. consumers to oil producers outside of the U.S. There was some debate among economists as to whether the U.S. exercise of its monopsony power in oil markets, for example from the implementation of LDV GHG rules, was a "transfer payment" or a "benefit". Given the redistributive nature of this monopsony impact from a global perspective, and since there are no changes in resource production costs when the U.S. exercises it monopsony power, some economists argued that it is a transfer payment. Other economists argued that monopsony impacts were a benefit since they partially address, and partially offset, the market power of OPEC. In previous EPA LDV GHG rules, after weighing both countervailing arguments, EPA concluded that the U.S.'s exercise of its monopsony power was a transfer payment, and not a benefit.[94]

In the context of this LDV GHG rule, the U.S.'s oil trade balance is quite a bit different than in previous LDV GHG rules. The U.S. is projected to be a net exporter of oil in the time frame of this analysis of this rule, 2023-2050. As a result, reductions in U.S. oil consumption and, in turn, U.S. oil imports, still lower the world oil price modestly. But the net effect of the lower world oil price is now a decrease in revenue for U.S. exporters of crude oil and products, instead of a decrease in payments to foreign oil producers. The argument that monopsony impacts address the market power of OPEC is no longer appropriate. Thus, EPA continues to consider the U.S. exercise of monopsony power to be transfer payments. As a result, EPA does not believe that excluding monopsony effects stemming from this rule results in an underestimate of the energy security benefits of this rule.

For this rule, EPA and ORNL worked together to develop oil security premiums based upon the recent energy security literature on this topic. EPA is continuing to use the same oil security premium methodology for this final rule as it used in the proposal. The recent economics literature (discussed in Section 3.2.2 above) focuses on three factors that can influence the macroeconomic oil security premiums. We discuss each factor below and provide a rationale for how we are updating two out of three of the factors to develop new estimates of the macroeconomic oil security premiums. We are not accounting for how shale oil is influencing the macroeconomic oil security premiums in this final rule.

First, we assess the price elasticity of demand for oil. In previous EPA vehicle rulemakings, EPA has used a short-run elasticity of demand for oil of -0.045.[95] From the recent RFF study, the "blended" price elasticity of demand for oil is -0.05. The ORNL meta-analysis estimate of this parameter is -0.07. We find the elasticity estimates from what RFF characterizes as the "new literature," -0.175, and from the "new models" that RFF uses, -0.20 to -0.33, somewhat high. Most of the world's oil demand is concentrated in the transportation sector and there are currently limited alternatives to oil use in this sector. According to the IEA, the share of global oil consumption attributed to the transportation sector grew from 60 percent in 2000 to 66 percent in 2018.[96] The next largest sector by oil consumption, and an area of recent growth, is petrochemicals. Thus, we believe it would be surprising if short-run oil demand responsiveness has changed in a dramatic fashion. Increases in future electric vehicle use could influence the price elasticity of demand for oil, but there is little empirical evidence available to assess this issue. We may attempt to address this issue in the future if new information and data becomes available.

The ORNL meta-analysis estimate encompasses the full range of the economics literature on this topic and develops a meta-analysis estimate from the results of many different studies in a structured way, while the RFF study's "new models" results represent only a small subset of the economics literature's estimates. Thus, for the analysis of this final rule, we are increasing the short-run price elasticity of demand for oil from -0.045 to -0.07, a 56 percent increase.[1] This increase has the effect of lowering the macroeconomic oil security premiums estimated for this rulemaking.

Second, we consider the elasticity of GDP to an oil price shock. For previous EPA vehicle rulemakings, a GDP elasticity to an oil shock of -0.032 was used.[97] The RFF "blended" GDP elasticity is -0.028, the RFF's "new literature" GDP elasticity is -0.018, while the RFF "new models" GDP elasticities range from -0.007 to -0.027. The ORNL meta-analysis GDP elasticity is -0.021, a 35 percent reduction from the GDP elasticity used in previous EPA rulemakings. We believe that the ORNL meta-analysis value is representative of the recent literature on this topic since it considers a wide range of recent studies and does so in a structured way. Also, the ORNL meta-analysis estimate is within the range of GDP elasticities of RFF's "blended" and "new literature" elasticities.

For the proposed rule, energy security premiums were developed using the ORNL methodology, the AEO 2018 and a GDP elasticity of -0.023. For this final rule, in addition to updating the energy security premium estimates to use the most recently available AEO (i.e., AEO 2021), we have also updated the GDP elasticity to -0.021, the value from the ORNL meta-analysis discussed above. These updates resulted in a lower per-barrel energy security premium than was used in the analysis for the proposed rule. Note, however, that the overall energy security benefits are greater in this final rule than in the proposal because the final standards are estimated to result in a greater reduction of gasoline consumption, which more than offsets the decrease to the per-barrel premium. Finally, we have not factored in how increases in U.S. tight oil might influence U.S. oil security values, other than how they significantly reduce net oil imports, given the complexity of this issue.

Table 3-6 below provides estimates of ORNL's macroeconomic oil security premiums for selected years from 2023–2050 based upon the AEO 2021. In terms of cents per gallon, the macroeconomic oil security premiums range from 7.5 cents/gallon in 2023 to 7.7 cents/gallon in 2026. In the later years of the time frame of this analysis, the macroeconomic oil security premiums range from 8.1 cents/gallon in 2030 to 11.8 cents/gallon in 2050.

[1] EPA and ORNL worked together to develop an updated estimate of the short-run elasticity of demand for oil for use in the ORNL model.

Table 3-6: Macroeconomic Oil Security Premiums for Selected Years from 2023–2050 (2018$/Barrel)*

Year (range)	Macroeconomic Oil Security Premiums (Range)
2023	$3.15 ($0.92 – $5.71)
2024	$3.17 ($0.84 – $5.80)
2025	$3.18 ($0.77 – $5.89)
2026	$3.23 ($0.74 – $6.00)
2030	$3.41 ($0.62 – $6.41)
2035	$3.76 ($0.70 – $7.05)
2040	$4.21 ($1.04 – $7.77)
2045	$4.54 ($1.18 – $8.29)
2050	$4.94 ($1.46 – $8.91)
* Top values in each cell are the midpoints, the values in parentheses are the 90 percent confidence intervals. The macroeconomic oil security premium estimates for the years 2023, 2024 and 2026 are linearly interpolated values from ORNL estimates, which are reported in five-year time intervals.	

3.2.6 <u>Energy Security Benefits of the Final Rule</u>

Using the ORNL oil security premium methodology with: (1) estimated oil savings calculated by EPA, (2) an oil import reduction factor of 91 percent, and (3) updated oil security premium estimates based upon the recent energy security literature and the AEO 2021, EPA presents the annual energy security benefits of the final LDV GHG standards for selected years from 2023–2050 in Table 3–7 below. We do not consider the monopsony effect or military cost impacts of oil import changes in the energy security benefits provided below.

Table 3-7: Annual Energy Security Benefits of the Final LDV GHG/Fuel Economy Rule for Selected Years 2023-2050 (in Billions of 2018$)

Year	Benefits (2018$)
2023	$0.03
2026	$0.18
2030	$0.51
2035	$0.92
2040	$1.3
2050	$1.6
PV, 3%	$14
PV, 7%	$7
Annualized, 3%	$0.73
Annualized, 7%	$0.56

3.3 Social Cost of Greenhouse Gases

We estimate the climate benefits for this rulemaking using measures of the social cost of three greenhouse gases: carbon, methane, and nitrous oxide. The social cost of each gas (i.e., the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O)) is the monetary value of the net harm to society associated with a marginal increase in emissions in a given year, or the benefit of avoiding that increase. Collectively, these values are referenced as the "social cost of greenhouse gases" (SC-GHG). In principle, SC-GHG includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG therefore, reflects the societal value of reducing emissions of the gas in question by one metric ton. The SC-GHG is the theoretically appropriate values to use in conducting benefit-cost analyses of policies that affect CO_2, CH_4, and N_2O emissions.

We estimate the global social benefits of CO_2, CH_4, and N_2O emission reductions expected from this final rule using the SC-GHG estimates presented in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. We have evaluated the SC-GHG estimates in the TSD and have determined that these estimates are appropriate for use in estimating the global social benefits of CO_2, CH_4, and N_2O emission reductions expected from this final rule.[98] These SC-GHG estimates are interim values developed for use in benefit-cost analyses until updated estimates of the impacts of climate change can be developed based on the best available science and economics. After considering the TSD, and the issues and studies discussed therein, EPA finds that these estimates, while likely an underestimate, are the best currently available SC-GHG estimates. The SC-GHG estimates used in this RIA are the same as those used in the July 2016 Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025, adjusted for inflation to 2018 dollars.

The SC-GHG estimates presented here were developed over many years, using transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, in 2009, an interagency working group (IWG) that included the EPA and other executive branch agencies and offices was established to ensure that agencies were using the best available science. The IWG published SC-CO_2 estimates in 2010 that were developed from an ensemble of three widely cited integrated assessment models (IAMs) that estimate global climate damages using highly aggregated representations of climate processes and the global economy combined into a single modeling framework. The three IAMs were run using a common set of input assumptions in each model for future population, economic, and CO_2 emissions growth, as well as equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. These estimates were updated in 2013 based on new versions of each IAM.[99,100,101] In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) using methodologies that are consistent with the methodology underlying the SC-CO_2 estimates. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO_2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO_2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide,* and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process.[102] Shortly thereafter, in March 2017, President Trump issued Executive Order 13783, which disbanded the IWG, withdrew the previous TSDs, and directed agencies to ensure SC-CO_2 estimates used in regulatory analyses are consistent with the guidance contained in OMB's Circular A-4, "including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates" (E.O. 13783, Section 5(c)). Benefit-cost analyses following E.O. 13783, including the benefit-cost analysis in the SAFE rule RIA[m], used SC-CO_2 estimates that attempted to focus on the domestic impacts of climate change as estimated by the models to occur within U.S. borders and were calculated using two discount rates recommended by Circular A-4, 3 percent and 7 percent. All other methodological decisions and model versions used in SC- CO_2 calculations remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued Executive Order 13990, which re-established the IWG and directed it to ensure that the U.S. Government's estimates of the social cost of carbon and other greenhouse gases reflect the best available science and the recommendations of the National Academies.[103] The IWG was tasked with first reviewing the SC-GHG estimates currently used in Federal analyses and publishing interim estimates within 30 days of the E.O. that reflect the full impact of GHG emissions, including by taking global damages into account. As noted above, EPA participated in the IWG but has also independently evaluated the interim SC-GHG estimates published in February 2021 and determined they are appropriate to use here to estimate the climate benefits for this final rule. EPA and other agencies intend to undertake a fuller update of the SC-GHG estimates that takes into consideration the advice of the National Academies and other recent scientific literature.[103]

The EPA has also evaluated the content of the TSD, including the studies and methodological issues discussed therein and concludes that it agrees with the rationale for these estimates presented in the TSD and summarized below.

In particular, the IWG found that the SC-GHG estimates used under E.O. 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG found that a global perspective is essential for SC-GHG estimates because climate impacts occurring outside U.S. borders can directly and indirectly affect the welfare of U.S. citizens and residents. Thus, U.S. interests are affected by the climate impacts that occur outside U.S. borders. Examples of affected interests include direct effects on U.S. citizens and assets located abroad, international trade, U.S. military assets and interests abroad, and tourism, and spillover pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns. In addition, assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may

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[m] The values used in the SAFE rule RIA were interim values developed under E.O. 13783 for use in regulatory analyses. EPA followed E.O. 13783 in the SAFE rule by using SC-CO_2 estimates reflecting impacts occurring within U.S. borders and 3% and 7% discount rates in our central analysis for the SAFE rule RIA.

affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents.

In addition, a wide range of scientific and economic experts have emphasized the issue of reciprocity as support for considering global damages of GHG emissions. Using a global estimate of damages in U.S. analyses of regulatory actions allows the U.S. to continue to actively encourage other nations, including emerging major economies, to take significant steps to reduce emissions. The only way to achieve an efficient allocation of resources for emissions reduction on a global basis—and so benefit the U.S. and its citizens—is for all countries to base their policies on global estimates of damages.

Therefore, in this final rule EPA centers attention on a global measure of SC-GHG. This approach is the same as that taken in EPA regulatory analyses over 2009 through 2016. Furthermore, as an empirical matter, the development of a domestic SC-GHG is greatly complicated by the relatively few region- or country-specific estimates of the SC-CO2 in the literature. At present, the only quantitative characterization of domestic damages from GHG emissions is based on the share of damages arising from climate impacts occurring within U.S. borders as represented in current IAMs. This is both incomplete and an underestimate of the share of total damages that accrue to the citizens and residents of the U.S. because these models do not capture the regional interactions and spillovers discussed above. EPA, as a member of the IWG, will continue to review developments in the literature, including more robust methodologies for estimating SC-GHG values based on purely domestic damages, and explore ways to better inform the public of the full range of carbon impacts, both global and domestic.

Second, the IWG found that the use of the social rate of return on capital (7 percent under current OMB Circular A-4 guidance) to discount the future benefits of reducing GHG emissions inappropriately underestimates the impacts of climate change for the purposes of estimating the SC-GHG. Consistent with the findings of the National Academies and the economic literature, the IWG continued to conclude that the consumption rate of interest is the theoretically appropriate discount rate in an intergenerational context (IWG 2010, 2013, 2016a, 2016b), and recommended that discount rate uncertainty and relevant aspects of intergenerational ethical considerations be accounted for in selecting future discount rates.[n,103,103,104,105,106] Furthermore, the damage estimates developed for use in the SC-GHG are estimated in consumption-equivalent terms, and so an application of OMB Circular A-4's guidance for regulatory analysis would then use the consumption discount rate to calculate the SC-GHG. EPA agrees with this assessment and will continue to follow developments in the literature pertaining to this issue. EPA also notes that while OMB Circular A-4, as published in 2003, recommends using 3% and 7% discount rates as "default" values, Circular A-4 also reminds agencies that "different regulations may call

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[n] GHG emissions are stock pollutants, where damages are associated with what has accumulated in the atmosphere over time, and they are long lived such that subsequent damages resulting from emissions today occur over many decades or centuries depending on the specific greenhouse gas under consideration. In calculating the SC-GHG, the stream of future damages to agriculture, human health, and other market and non-market sectors from an additional unit of emissions are estimated in terms of reduced consumption (or consumption equivalents). Then that stream of future damages is discounted to its present value in the year when the additional unit of emissions was released. Given the long time horizon over which the damages are expected to occur, the discount rate has a large influence on the present value of future damages.

for different emphases in the analysis, depending on the nature and complexity of the regulatory issues and the sensitivity of the benefit and cost estimates to the key assumptions." On discounting, Circular A-4 recognizes that "special ethical considerations arise when comparing benefits and costs across generations," and Circular A-4 acknowledges that analyses may appropriately "discount future costs and consumption benefits…at a lower rate than for intragenerational analysis." In the 2015 Response to Comments on the Social Cost of Carbon for Regulatory Impact Analysis, OMB, EPA, and the other IWG members recognized that "Circular A-4 is a living document" and "the use of 7 percent is not considered appropriate for intergenerational discounting. There is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself." Thus, EPA concludes that a 7% discount rate is not appropriate to apply to value the social cost of greenhouse gases in this regulatory analysis. In this analysis, to calculate the present and annualized values of climate benefits, EPA uses the same discount rate as the rate used to discount the value of damages from future GHG emissions, for internal consistency. That approach to discounting follows the same approach that the February 2021 TSD recommends "to ensure internal consistency—i.e., future damages from climate change using the SC-GHG at 2.5 percent should be discounted to the base year of the analysis using the same 2.5 percent rate." EPA has also consulted the National Academies' 2017 recommendations on how SC-GHG estimates can "be combined in RIAs with other cost and benefits estimates that may use different discount rates." The National Academies reviewed "several options," including "presenting all discount rate combinations of other costs and benefits with [SC-GHG] estimates." In Table 10-6, EPA presents all combinations of the SC-GHG values at the different discount rates appropriate to climate effects (2.5%, 3%, and 5%) together with other costs and benefits discounted at the 3% and 7% rates, consistent with the options outlined by the National Academies.

While the IWG works to assess how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates, it adopted as interim estimates the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The estimates rely on the same models and harmonized inputs and are calculated using a range of discount rates. As explained in the February 2021 TSD, the IWG has determined that it is appropriate for agencies to revert to the same set of four values drawn from the SC-GHG distributions based on three discount rates as were used in regulatory analyses between 2010 and 2016 and subject to public comment. For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then selected a set of four values for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5 percent, 3 percent, and 5 percent), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3 percent estimate of the discount rate. As explained in the February 2021 TSD, this update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

Table 3-8, Table 3-9, and Table 3-10 summarize the interim global SC-CO_2, SC-CH_4, and SC-N_2O estimates for the years 2015 to 2070.[o] These estimates are reported in 2018 dollars but are otherwise identical to those presented in the IWG's 2016 TSD. For purposes of capturing uncertainty around the SC-GHG estimates in analyses, the IWG's February 2021 TSD emphasizes the importance of considering all four of the SC-GHG values. The SC-GHG increases over time within the models – i.e., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025 – because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP.

Table 3-8: Interim Global Social Cost of Carbon Values, 2020-2070 (2018$/Metric Tonne CO_2)[99]

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	$14	$50	$74	$147
2025	$16	$55	$81	$164
2030	$19	$60	$87	$181
2035	$22	$66	$93	$200
2040	$24	$71	$100	$218
2045	$28	$77	$107	$235
2050	$31	$82	$113	$252
2055	$34	$86	$119	$258
2060	$37	$91	$124	$268
2065	$42	$98	$132	$292
2070	$48	$105	$139	$318

Note: The 2020-2050 SC-CO_2 values are identical to those reported in the 2016 TSD (IWG 2016a) adjusted for inflation to 2018 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9 (U.S. BEA 2021). The estimates were extended for the period 2051 to 2070 using methods, assumptions, and parameters identical to the 2020-2050 estimates. The values are stated in $/metric tonne CO_2 and vary depending on the year of CO_2 emissions. This table displays the values rounded to the nearest dollar; the annual unrounded values through 2050 are available on OMB's website: <https://www.whitehouse.gov/briefing-room/blog/2021/02/26/a-return-to-science-evidence-based-estimates-of-the-benefits-of-reducing-climate-pollution/>. The annual unrounded 2051-2070 values used in the calculations in this RIA are available in the rule docket.

[o] The February 2021 TSD provides SC-GHG estimates through emissions year 2050. Estimates were extended for the period 2051 to 2070 using the IWG methods, assumptions, and parameters identical to the 2020-2050 estimates. Specifically, 2051-2070 SC-GHG estimates were calculated in Mimi.jl, an open-source modular computing platform used for creating, running, and performing analyses on IAMs (www.mimiframework.org). For CO_2, the 2051-2054 SC-GHG values were calculated by linearly interpolating between the 2050 TSD values and the 2055 Mimi-based values. The annual unrounded 2051-2070 values used in the calculations in this RIA are available in the rule docket, and the replication code is available upon request.

Table 3-9: Interim Global Social Cost of Methane Values, 2020-2070 (2018$/Metric Tonne CH_4) [99]

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	$650	$1,400	$1,900	$3,800
2025	$780	$1,700	$2,200	$4,400
2030	$910	$1,900	$2,400	$5,000
2035	$1,100	$2,200	$2,700	$5,800
2040	$1,200	$2,400	$3,100	$6,500
2045	$1,400	$2,700	$3,400	$7,200
2050	$1,600	$3,000	$3,700	$7,900
2055	$1,700	$3,100	$3,800	$8,100
2060	$1,800	$3,300	$4,000	$8,300
2065	$2,400	$4,100	$4,800	$11,000
2070	$3,000	$4,800	$5,700	$14,000

Note: The 2020-2050 SC-CH_4 values are identical to those reported in the 2016 TSD (IWG 2016a) adjusted for inflation to 2018 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9 (U.S. BEA 2021). The estimates were extended for the period 2051 to 2070 using methods, assumptions, and parameters identical to the 2020-2050 estimates. The values are stated in $/metric tonne CH_4 and vary depending on the year of CH_4 emissions. This table displays the values rounded to the nearest dollar; the annual unrounded values through 2050 are available on OMB's website: <https://www.whitehouse.gov/briefing-room/blog/2021/02/26/a-return-to-science-evidence-based-estimates-of-the-benefits-of-reducing-climate-pollution/>. The annual unrounded 2051-2070 values used in the calculations in this RIA are available in the rule docket.

Table 3-10: Interim Global Social Cost of Nitrous Oxide Values, 2020-2070 (2018$/Metric Tonne N_2O) [99]

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	$5,600	$18,000	$26,000	$47,000
2025	$6,600	$20,000	$29,000	$53,000
2030	$7,600	$22,000	$32,000	$59,000
2035	$8,800	$24,000	$35,000	$65,000
2040	$10,000	$27,000	$38,000	$72,000
2045	$11,000	$29,000	$41,000	$79,000
2050	$13,000	$32,000	$44,000	$86,000
2055	$14,000	$35,000	$47,000	$92,000
2060	$16,000	$37,000	$50,000	$98,000
2065	$19,000	$42,000	$55,000	$110,000
2070	$22,000	$46,000	$60,000	$130,000

Note: The 2020-2050 SC-N_2O values are identical to those reported in the 2016 TSD (IWG 2016a) adjusted for inflation to 2018 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9 (U.S. BEA 2021). The estimates were extended for the period 2051 to 2070 using methods, assumptions, and parameters identical to the 2020-2050 estimates. The values are stated in $/metric tonne N_2O and vary depending on the year of N_2O emissions. This table displays the values rounded to the nearest dollar; the annual unrounded values through 2050 are available on OMB's website: <https://www.whitehouse.gov/briefing-room/blog/2021/02/26/a-return-to-science-evidence-based-estimates-of-the-benefits-of-reducing-climate-pollution/>. The annual unrounded 2051-2070 values used in the calculations in this RIA are available in the rule docket.

There are a number of limitations and uncertainties associated with the SC-GHG estimates presented in Table 3-8 through Table 3-10. Some uncertainties are captured within the analysis, while other areas of uncertainty have not yet been quantified in a way that can be modeled. Figure 3-1, Figure 3-2, and Figure 3-3 present the quantified sources of uncertainty in the form of frequency distributions for the SC-CO_2, SC-CH_4, and SC-N_2O estimates for emissions in 2030. The distributions of SC-GHG estimates reflect uncertainty in key model parameters such as the equilibrium climate sensitivity, as well as uncertainty in other parameters set by the original model developers. To highlight the difference between the impact of the discount rate and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-GHG estimates for each discount rate. As illustrated by the figures, the assumed discount rate plays a critical role in the ultimate estimate of the SC-GHG. This is because GHG emissions today continue to impact society far out into the future, so with a higher discount rate, costs that accrue to future generations are weighted less, resulting in a lower estimate. As discussed in the February 2021 TSD, there are other sources of uncertainty that have not yet been quantified and are thus not reflected in these estimates.

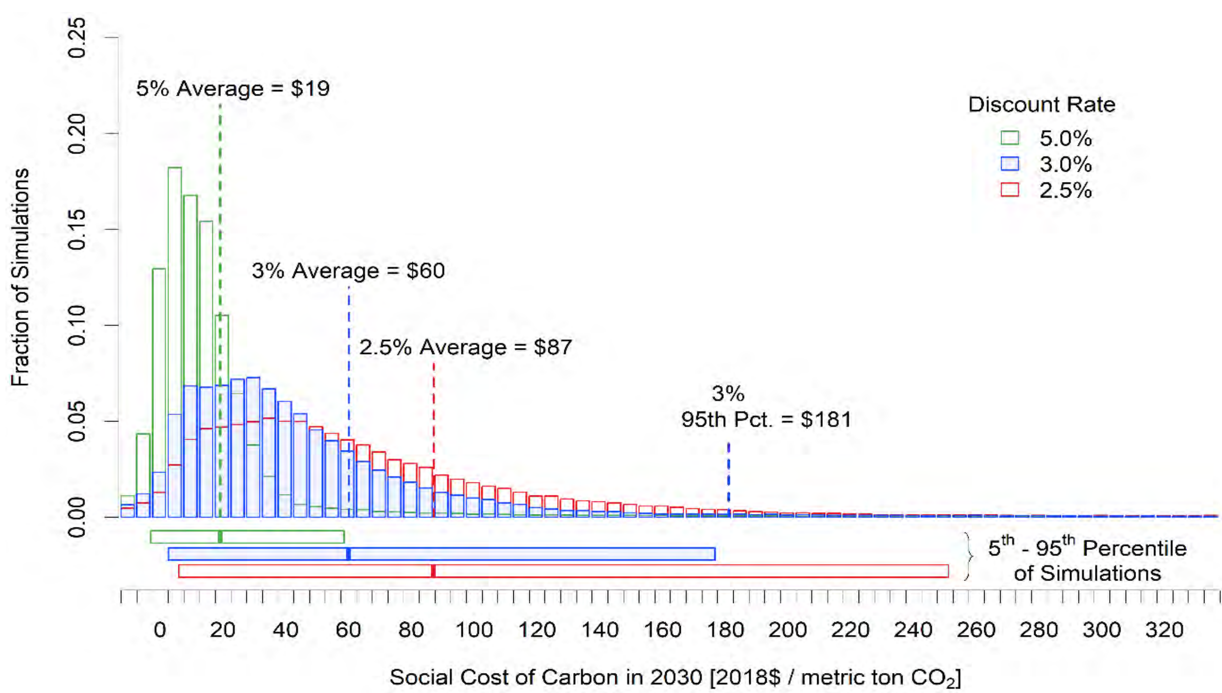

Figure 3-1: Frequency Distribution of SC-CO_2 Estimates for 2030 [p]

[p] Although the distributions and numbers are based on the full set of model results (150,000 estimates for each discount rate and gas), for display purposes the horizontal axis is truncated with 0.02 to 0.68 percent of the estimates falling below the lowest bin displayed and 0.12 to 3.11 percent of the estimates falling above the highest bin displayed, depending on the discount rate and GHG.

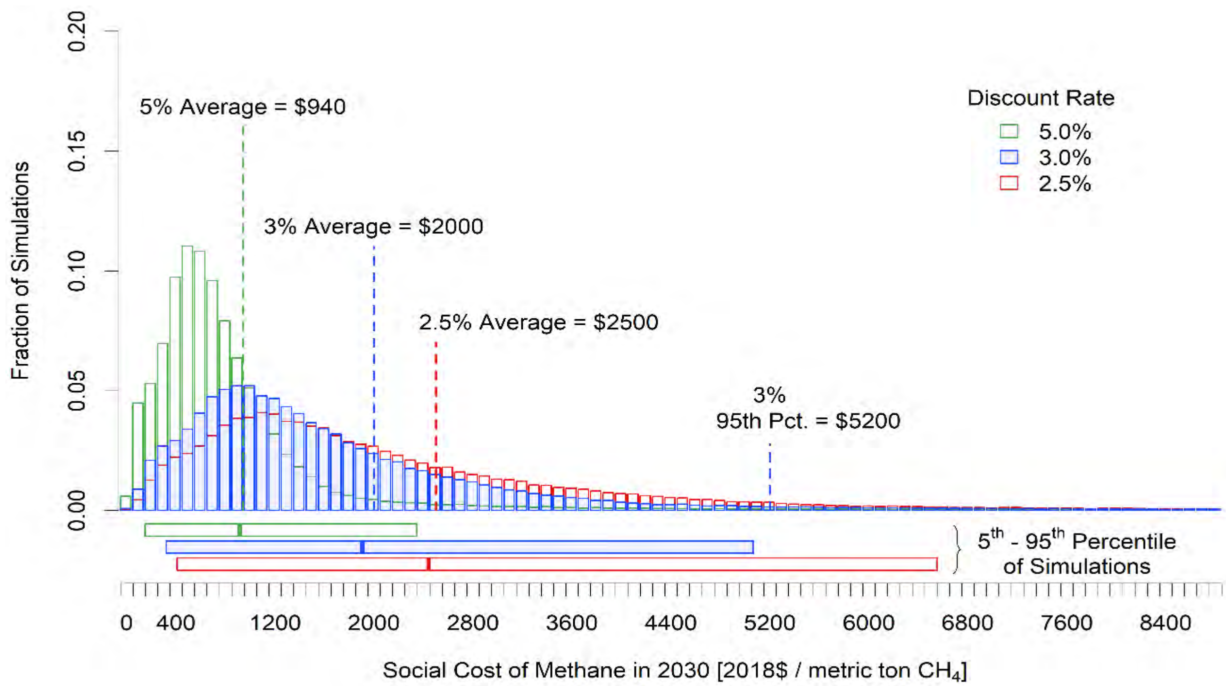

Figure 3-2: Frequency Distribution of SC-CH_4 Estimates for 2030[l]

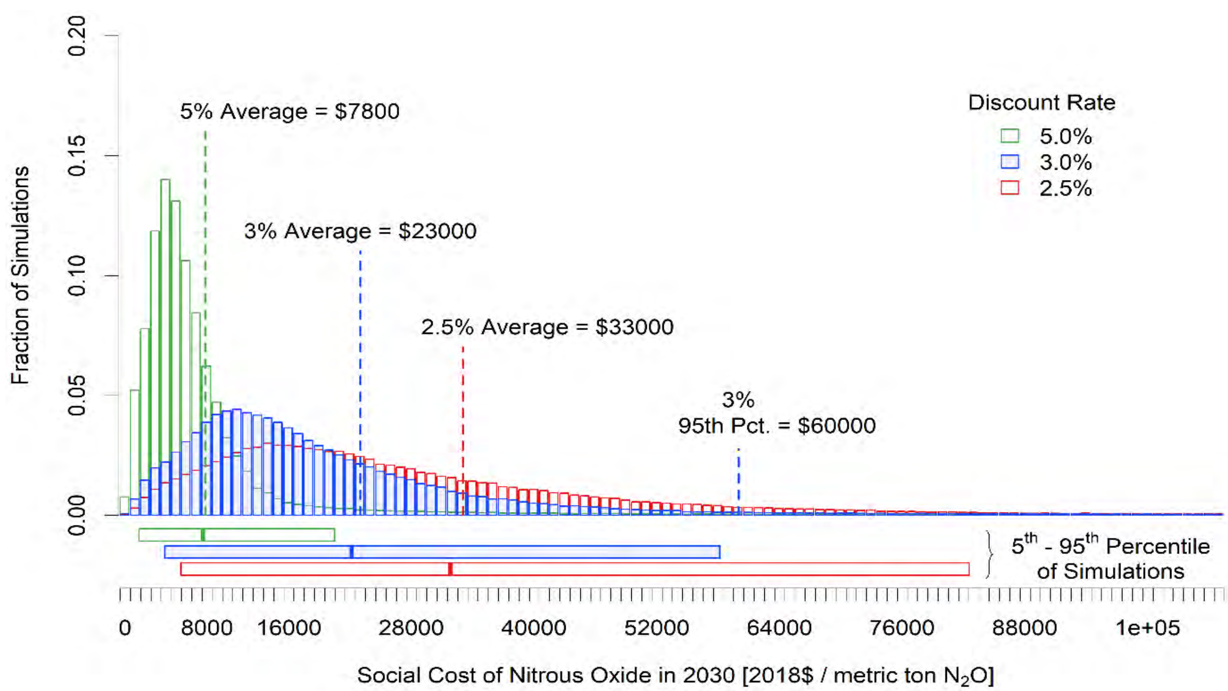

Figure 3-3: Frequency Distribution of SC-N_2O Estimates for 2030[l]

The interim SC-GHG estimates presented in Table 3-8 through Table 3-10 have a number of other limitations. First, the current scientific and economic understanding of discounting approaches suggests discount rates appropriate for intergenerational analysis in the context of climate change are likely to be less than 3 percent, near 2 percent or lower.[107] Second, the IAMs used to produce these interim estimates do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature and the science underlying their "damage functions" – i.e., the core parts of the IAMs that map global mean temperature changes and other physical impacts of climate change into economic (both market and nonmarket) damages–lags behind the most recent research. For example, limitations include the incomplete treatment of catastrophic and non-catastrophic impacts in the integrated assessment models, their incomplete treatment of adaptation and technological change, the incomplete way in which inter-regional and intersectoral linkages are modeled, uncertainty in the extrapolation of damages to high temperatures, and inadequate representation of the relationship between the discount rate and uncertainty in economic growth over long time horizons. Likewise, the socioeconomic and emissions scenarios used as inputs to the models do not reflect new information from the last decade of scenario generation or the full range of projections.

The modeling limitations do not all work in the same direction in terms of their influence on the SC-GHG estimates. However, as discussed in the February 2021 TSD, the IWG has recommended that, taken together, the limitations suggest that the SC-GHG estimates used in this final rule likely underestimate the damages from GHG emissions. EPA concurs that the values used in this rulemaking conservatively underestimate the rule's climate benefits. In particular, the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, which was the most current IPCC assessment available at the time when the IWG decision over the ECS input was made, concluded that SC-CO_2 estimates "very likely…underestimate the damage costs" due to omitted impacts.[107] Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC's Fifth Assessment report and other recent scientific assessments.[108,109,110,111,112,113,114,115] These assessments confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. For example, sea level rise projections from the IPCC's Fourth Assessment report ranged from 18 to 59 centimeters by the 2090s relative to 1980-1999, while excluding any dynamic changes in ice sheets due to the limited understanding of those processes at the time.[108] A decade later, the Fourth National Climate Assessment projected a substantially larger sea level rise of 30 to 130 centimeters by the end of the century relative to 2000, while not ruling out even more extreme outcomes.[114] The February 2021 TSD briefly previews some of the recent advances in the scientific and economic literature that the IWG is actively following and that could provide guidance on, or methodologies for, addressing some of the limitations with the interim SC-GHG estimates. The IWG is currently working on a comprehensive update of the SC-GHG estimates taking into consideration recommendations from the National Academies of Sciences, Engineering and Medicine, recent scientific literature, public comments received on the February 2021 TSD and other input from experts and diverse stakeholder groups.[116]

Table 3-11 through Table 3-13 shows the estimated global climate benefits from changes in CO_2, CH_4, N_2O, respectively and Table 3-14 through Table 3-16 shows the combined total climate benefits expected to occur over 2023-2070 under the final revised GHG standards and the two alternatives analyzed (see Chapter 2.2.2 and also Preamble Section II.C for more detail on the alternatives considered by EPA). EPA estimated the dollar value of the GHG-related effects for each analysis year between 2023 through 2050 by applying the SC-GHG estimates, shown in Tables 3-8 through 3-10, to the estimated changes in GHG emissions inventories resulting from including tailpipe emissions from light-duty cars and trucks, and the upstream emissions associated with the fuels used to power those vehicles.[q] EPA then calculated the present value and annualized benefits from the perspective of 2021 by discounting each year-specific value to the year 2021 using the same discount rate used to calculate the SC-GHG.

[q] According to OMB's Circular A-4 (2003), an "analysis should focus on benefits and costs that accrue to citizens and residents of the United States", and international effects should be reported separately. Circular A-4 also reminds analysts that "[d]ifferent regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues." To correctly assess the total climate damages to U.S. citizens and residents, an analysis must account for impacts that occur within U.S. borders, climate impacts occurring outside U.S. borders that directly and indirectly affect the welfare of U.S. citizens and residents, how U.S. GHG mitigation activities affect mitigation activities by other countries, and spillover effects from climate action elsewhere. The SC-GHG estimates used in regulatory analysis under revoked E.O. 13783, including in the RIA for the SAFE rule, were an attempt to approximate the climate damages occurring within U.S. borders only (e.g., \$7/mtCO_2 and \$11/mtCO_2 (2018 dollars) using a 3% discount rate for emissions occurring in 2023 and 2050, respectively; \$207/mtCH_4 and \$376/mtCH_4 (2018 dollars) using a 3% discount rate for emissions occurring in 2023 and 2050, respectively; and \$2437/mtN_2O and \$3986/mtN_2O (2018 dollars) using a 3% discount rate for emissions occurring in 2023 and 2050, respectively). Applying the same estimates that were used in the SAFE rule (based on a 3% discount rate) to the GHG emission reduction expected from this final rule would yield benefits from climate impacts within U.S borders of \$37 million in 2023, increasing to \$1.9 billion in 2050 for CO_2; \$1 million in 2023, increasing to \$67 million in 2050 for CH_4; \$0.3 million in 2023, increasing to \$15 million in 2050 for N_2O; and combined GHG benefits of \$38 million in 2023, increasing to \$1.9 billion in 2050. However, as discussed at length in the IWG's February 2021 TSD, estimates focusing on the climate impacts occurring solely within U.S. borders are an underestimate of the benefits of GHG mitigation accruing to U.S. citizens and residents, as well as being subject to a considerable degree of uncertainty due to the manner in which they are derived. In particular, the estimates developed under revoked E.O. 13783 did not capture significant regional interactions, spillovers, and other effects and so are incomplete underestimates. The U.S. District Court for the Northern District of California found that by omitting such impacts, those "interim domestic" estimates "fail[ed] to consider…important aspect[s] of the problem" and departed from the "best science available" as reflected in the global estimates. California v. Bernhardt, 472 F. Supp. 3d 573, 613-14 (N.D.Cal. 2020). EPA continues to center attention in this regulatory analysis on the global measures of the SC-GHG as the appropriate estimates and as necessary for all countries to use to achieve an efficient allocation of resources for emissions reduction on a global basis, and so benefit the U.S. and its citizens.

Table 3-11: Estimated Global Climate Benefits from Changes in CO_2 Emissions 2023 – 2050 for the Final Rule (Billions of 2018$)

	Discount Rate and Statistic			
Calendar Year	5% Average	3% Average	2.5% Average	% 95th percentile
2023	$0.076	$0.26	$0.38	$0.77
2024	$0.16	$0.53	$0.78	$1.6
2025	$0.28	$0.94	$1.4	$2.8
2026	$0.45	$1.5	$2.2	$4.5
2027	$0.67	$2.2	$3.2	$6.6
2028	$0.92	$3	$4.3	$9
2029	$1.2	$3.7	$5.4	$11
2030	$1.4	$4.4	$6.4	$13
2031	$1.6	$5.2	$7.5	$16
2032	$1.9	$5.9	$8.5	$18
2033	$2.2	$6.6	$9.5	$20
2034	$2.4	$7.3	$11	$22
2035	$2.6	$8	$11	$24
2036	$2.9	$8.6	$12	$26
2037	$3.1	$9.2	$13	$28
2038	$3.3	$9.7	$14	$30
2039	$3.5	$10	$14	$31
2040	$3.7	$11	$15	$33
2041	$3.9	$11	$16	$34
2042	$4	$11	$16	$35
2043	$4.2	$12	$17	$36
2044	$4.3	$12	$17	$37
2045	$4.5	$12	$17	$38
2046	$4.6	$13	$18	$39
2047	$4.7	$13	$18	$40
2048	$4.9	$13	$18	$40
2049	$5	$13	$18	$41
2050	$5.1	$14	$19	$42
PV	$29	$120	$190	$370
Annualized	$1.9	$6.3	$9.1	$19

Notes:
Climate benefits are based on changes (reductions) in CO_2 emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2 estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

Table 3-12: Estimated Global Climate Benefits from Changes in CH_4 Emissions 2023 – 2050 for the Final Rule (Billions of 2018$)

	Discount Rate and Statistic			
Calendar Year	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.0037	$0.0081	$0.011	$0.021
2024	$0.0076	$0.016	$0.021	$0.043
2025	$0.014	$0.029	$0.038	$0.077
2026	$0.022	$0.047	$0.061	$0.12
2027	$0.033	$0.07	$0.09	$0.19
2028	$0.045	$0.096	$0.12	$0.25
2029	$0.058	$0.12	$0.15	$0.32
2030	$0.07	$0.15	$0.19	$0.39
2031	$0.083	$0.17	$0.22	$0.46
2032	$0.097	$0.2	$0.25	$0.53
2033	$0.11	$0.22	$0.29	$0.6
2034	$0.12	$0.25	$0.32	$0.67
2035	$0.14	$0.28	$0.35	$0.74
2036	$0.15	$0.3	$0.38	$0.8
2037	$0.16	$0.32	$0.41	$0.86
2038	$0.17	$0.34	$0.43	$0.92
2039	$0.18	$0.36	$0.46	$0.97
2040	$0.2	$0.38	$0.48	$1
2041	$0.21	$0.4	$0.5	$1.1
2042	$0.22	$0.42	$0.52	$1.1
2043	$0.22	$0.43	$0.54	$1.2
2044	$0.23	$0.45	$0.56	$1.2
2045	$0.24	$0.46	$0.57	$1.2
2046	$0.25	$0.47	$0.59	$1.3
2047	$0.26	$0.49	$0.6	$1.3
2048	$0.27	$0.5	$0.62	$1.3
2049	$0.28	$0.52	$0.64	$1.4
2050	$0.29	$0.53	$0.65	$1.4
PV	$1.5	$4.4	$6	$12
Annualized	$0.099	$0.22	$0.29	$0.6

Climate benefits are based on changes (reductions) in CH_4 emissions and are calculated using four different estimates of the social cost of methane (SC-CH_4) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CH_4 estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

Table 3-13: Estimated Global Climate Benefits from Changes in N_2O Emissions 2023 – 2050 (Billions of 2018$)

Discount Rate and Statistic				
Calendar Year	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.0009	$0.0028	$0.0041	$0.0073
2024	$0.0019	$0.0057	$0.0084	$0.015
2025	$0.0034	$0.01	$0.015	$0.027
2026	$0.0056	$0.017	$0.024	$0.044
2027	$0.0082	$0.024	$0.035	$0.065
2028	$0.011	$0.033	$0.048	$0.088
2029	$0.014	$0.042	$0.06	$0.11
2030	$0.017	$0.05	$0.072	$0.13
2031	$0.02	$0.059	$0.084	$0.16
2032	$0.023	$0.067	$0.096	$0.18
2033	$0.027	$0.076	$0.11	$0.2
2034	$0.03	$0.084	$0.12	$0.22
2035	$0.033	$0.092	$0.13	$0.24
2036	$0.036	$0.1	$0.14	$0.27
2037	$0.039	$0.11	$0.15	$0.28
2038	$0.042	$0.11	$0.16	$0.3
2039	$0.044	$0.12	$0.17	$0.32
2040	$0.047	$0.13	$0.18	$0.33
2041	$0.049	$0.13	$0.18	$0.35
2042	$0.051	$0.14	$0.19	$0.36
2043	$0.053	$0.14	$0.2	$0.37
2044	$0.055	$0.14	$0.2	$0.39
2045	$0.057	$0.15	$0.21	$0.4
2046	$0.059	$0.15	$0.21	$0.41
2047	$0.061	$0.16	$0.22	$0.42
2048	$0.063	$0.16	$0.22	$0.43
2049	$0.065	$0.16	$0.22	$0.44
2050	$0.066	$0.17	$0.23	$0.44
PV	$0.36	$1.4	$2.2	$3.8
Annualized	$0.024	$0.073	$0.11	$0.2

Climate benefits are based on changes (reductions) in N_2O emissions and are calculated using four different estimates of the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

Table 3-14: Estimated Global Climate Benefits from Changes in GHG Emissions 2023 – 2050 (Billions of 2018$)

Discount Rate and Statistic				
Calendar Year	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.081	$0.27	$0.4	$0.8
2024	$0.17	$0.55	$0.81	$1.6
2025	$0.3	$0.97	$1.4	$2.9
2026	$0.48	$1.6	$2.3	$4.7
2027	$0.71	$2.3	$3.3	$6.9
2028	$0.97	$3.1	$4.5	$9.3
2029	$1.2	$3.9	$5.6	$12
2030	$1.5	$4.6	$6.7	$14
2031	$1.7	$5.4	$7.8	$16
2032	$2	$6.2	$8.9	$19
2033	$2.3	$6.9	$9.9	$21
2034	$2.6	$7.7	$11	$23
2035	$2.8	$8.4	$12	$25
2036	$3.1	$9	$13	$27
2037	$3.3	$9.6	$14	$29
2038	$3.5	$10	$14	$31
2039	$3.7	$11	$15	$33
2040	$3.9	$11	$16	$34
2041	$4.1	$12	$16	$36
2042	$4.3	$12	$17	$37
2043	$4.5	$12	$17	$38
2044	$4.6	$13	$18	$39
2045	$4.8	$13	$18	$40
2046	$4.9	$13	$18	$41
2047	$5.1	$14	$19	$41
2048	$5.2	$14	$19	$42
2049	$5.3	$14	$19	$43
2050	$5.5	$14	$20	$44
PV	$31	$130	$200	$390
Annualized	$2	$6.6	$9.5	$20

Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

Table 3-15: Estimated Global Climate Benefits from Changes in GHG Emissions 2023 – 2050 for the Proposal Standards (Billions of 2018$)

Discount Rate and Statistic				
Calendar Year	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.055	$0.18	$0.27	$0.55
2024	$0.12	$0.39	$0.57	$1.2
2025	$0.22	$0.72	$1.1	$2.1
2026	$0.34	$1.1	$1.6	$3.3
2027	$0.49	$1.6	$2.3	$4.8
2028	$0.66	$2.1	$3.1	$6.3
2029	$0.83	$2.6	$3.8	$7.8
2030	$0.99	$3.1	$4.5	$9.3
2031	$1.2	$3.6	$5.2	$11
2032	$1.3	$4.1	$5.9	$12
2033	$1.5	$4.6	$6.5	$14
2034	$1.7	$5	$7.2	$15
2035	$1.8	$5.5	$7.8	$17
2036	$2	$5.9	$8.4	$18
2037	$2.1	$6.3	$8.8	$19
2038	$2.3	$6.6	$9.3	$20
2039	$2.4	$6.9	$9.7	$21
2040	$2.5	$7.2	$10	$22
2041	$2.6	$7.4	$10	$23
2042	$2.7	$7.7	$11	$23
2043	$2.9	$7.9	$11	$24
2044	$3	$8.1	$11	$25
2045	$3.1	$8.3	$12	$25
2046	$3.1	$8.5	$12	$26
2047	$3.2	$8.7	$12	$27
2048	$3.3	$8.9	$12	$27
2049	$3.4	$9	$12	$28
2050	$3.5	$9.2	$13	$28
PV	$20	$83	$130	$250
Annualized	$1.3	$4.3	$6.2	$13

Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

Table 3-16: Estimated Global Climate Benefits from Changes in GHG Emissions 2023 – 2050 for Alternative 2 minus 10 (Billions of 2018$)

	Discount Rate and Statistic			
Calendar Year	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.12	$0.41	$0.6	$1.2
2024	$0.23	$0.77	$1.1	$2.3
2025	$0.37	$1.2	$1.8	$3.6
2026	$0.56	$1.8	$2.7	$5.5
2027	$0.79	$2.6	$3.7	$7.6
2028	$1.1	$3.4	$4.9	$10
2029	$1.3	$4.1	$6	$12
2030	$1.6	$4.9	$7.1	$15
2031	$1.8	$5.7	$8.2	$17
2032	$2.1	$6.4	$9.2	$19
2033	$2.4	$7.2	$10	$22
2034	$2.6	$7.9	$11	$24
2035	$2.9	$8.6	$12	$26
2036	$3.1	$9.2	$13	$28
2037	$3.3	$9.8	$14	$30
2038	$3.5	$10	$15	$31
2039	$3.7	$11	$15	$33
2040	$3.9	$11	$16	$34
2041	$4.1	$12	$16	$36
2042	$4.3	$12	$17	$37
2043	$4.5	$12	$17	$38
2044	$4.6	$13	$18	$39
2045	$4.8	$13	$18	$40
2046	$4.9	$13	$18	$41
2047	$5.1	$14	$19	$41
2048	$5.2	$14	$19	$42
2049	$5.3	$14	$19	$43
2050	$5.5	$14	$20	$44
PV	$32	$130	$200	$400
Annualized	$2.1	$6.7	$9.7	$20

Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

3.4 Drive Surplus, Congestion and Noise

As discussed in Chapter 3.1, the assumed rebound effect might occur when an increase in vehicle fuel efficiency encourages people to drive more as a result of the lower cost per mile of driving. Along with the safety considerations associated with increased vehicle miles traveled (described in Chapter 5.3), additional driving can lead to other costs and benefits that can be monetized.

The increase in travel associated with the rebound effect produces additional benefits to vehicle drivers, which reflect the value of the added (or more desirable) social and economic opportunities that become accessible with additional travel. Consistent with assumptions used in the NPRM, this analysis estimates the economic benefits from increased rebound-effect driving as the owner/operator surplus from the additional accessibility it provides.

The equation for the calculation of the Drive Value:

$$\textit{Drive Value} = (1/2)\,(VMTrebound)\,[(\$/mile)_{\text{NoAction}} - (\$/mile)_{\text{Action}}]$$

The economic value of the increased owner/operator surplus provided by added driving is estimated as one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven. Because it depends on the extent of improvement in fuel consumption, the value of benefits from increased vehicle use changes by model year and varies among alternative standards.

In contrast to the benefits of additional driving are the costs associated with that driving. If net operating costs of the vehicle decline, then we expect a positive rebound effect. Increased vehicle use associated with a positive rebound effect also contributes to increased traffic congestion and highway noise. Depending on how the additional travel is distributed throughout the day and where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled during peak periods. These added delays impose higher costs on other road users in the form of increased travel time and operating expenses. Because drivers do not take these external costs into account in deciding when and where to travel, we account for them separately as a cost of the added driving associated with the rebound effect.

EPA relies on estimates of congestion and noise costs developed by the Federal Highway Administration to estimate the increased external costs caused by added driving due to the rebound effect.[117] EPA employed estimates from this source previously in the analysis accompanying the light-duty 2010 and 2012 vehicle rulemakings and the 2016 Draft TAR and Proposed Determination. We continue to find them appropriate for this analysis after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values.

FHWA's congestion cost estimates focus on freeways because non-freeway effects are less serious due to lower traffic volumes and opportunities to re-route around the congestion. The agencies, however, applied the congestion cost to the overall VMT. The results of this analysis potentially overestimate the congestions costs associated with increased vehicle use, and thus lead to a conservative estimate of net benefits.

EPA has used FHWA's "Middle" estimates for marginal congestion and noise costs caused by increased travel from vehicles. This approach is consistent with the methodology used in our prior analyses. The values used are shown in Table 3-17.

These congestion costs are consistent with those used in the NPRM, the 2016 Draft TAR and the Proposed Determination. For this final rule, EPA has chosen not to adopt the approach from the SAFE FRM where scaling factors were used to adjust the underlying FHWA congestion cost estimates. In particular, EPA concluded that scaling the marginal per-mile congestion costs by the change in VMT per lane-mile on US highways from 1997 to 2017 does not account for changes in average speeds and improved road design, and may have the potential to over-estimate costs. We are using the FHWA congestion estimates without scaling, consistent with the SAFE NPRM and prior EPA rulemakings, and adjusting to represent 2018 dollars.

Table 3-17: Costs Associated with Congestion and Noise (2018 dollars per vehicle mile)

	Passenger cars	Van/SUVs	Pickups
Congestion	0.0634	0.0634	0.0566
Noise	0.0009	0.0009	0.0009

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Chapter 4: Modeling GHG Compliance

4.1 Compliance Modeling, Analytical Updates, and Analytical Revisions

The modeling runs presented within this RIA are not meant to be the sole technical justification underlying the revisions to the 2023-2026 GHG standards. That justification is also based upon nearly a decade of analyses presented by EPA in the 2010 and 2012 final rules, the 2016 Draft TAR, and during both the Proposed and Final Determinations.[1,2,3,4,5] Please see Chapter 1.2 for further discussion of these previous EPA analyses. EPA's extensive public record has made clear that more stringent GHG standards are both feasible at reasonable costs and result in significant GHG emission reductions and public health and welfare benefits. The analysis presented here is meant to show that, once again, when assessing standards of similar stringency to those set forth in the 2012 rule, the results are similar to those presented within previous EPA analyses. Those previous analytical results are summarized and discussed in Chapter 1 of this RIA.

To estimate compliance costs and the associated technology pathways that manufacturers might choose to comply with GHG standards, EPA has traditionally used its Optimization Model for reducing Emissions of Greenhouse Gases (OMEGA). However, in considering modeling tools to support the analysis for the proposed and final rulemaking, EPA has chosen to use the CAFE Compliance and Effects Modeling System (CCEMS) for modeling light-duty GHG compliance and costs for the revised MYs 2023-2026 GHG standards. As in the NPRM, for the final rule EPA has also chosen to use the same version of that model used in support of the SAFE FRM, with updates to inputs as described here. EPA made this choice for the following reasons:

- CCEMS has categorizations of technologies and model output formats that are distinct to the model, so continuing use of CCEMS for this rule has facilitated comparisons to the SAFE FRM.
- By using the same modeling tool as used in the SAFE rule, we can more clearly illustrate the influence of some of the key updates to the inputs used in the SAFE FRM.
- EPA considers the SAFE FRM version of the CCEMS model to be an effective modeling tool for purposes of assessing standards through the MY 2026 timeframe, along with changes to some of the key inputs as discussed below (see Table 4-2).

To be clear, modeling inputs are critically important to EPA analyses. As long as the underlying structure of a modeling tool is sound, which is the case with both CCEMS and with the OMEGA model, then it is not so much the specific tool used by EPA that is of paramount importance but the inputs for the tools that are of the most importance within our GHG compliance modeling efforts. This was made clear within the preamble to the SAFE FRM which stated, "inputs do not define models; models use inputs. Therefore, disagreements about inputs do not logically extend to disagreements about models. Similarly, while models determine resulting outputs, they do so based on inputs."[6] This statement was a response to public comments received on the SAFE NPRM, some of which argued that EPA should use its own modeling tools to support EPA actions. During development of the SAFE FRM, EPA staff had significant input on the CCEMS and considered the FRM version of the model, given changes made in response to public comments and EPA staff, to be a suitable modeling tool for that analysis. Similarly, we believe the SAFE FRM model and inputs, together with the key changes we've made since the SAFE FRM and in response to comments and analysis since our August 2021 NPRM, are appropriate for the particular analysis at hand in assessing standards through 2026.

EPA is also currently developing an updated version of OMEGA. In the development of this updated model, which we refer to as OMEGA2, we are placing emphasis on the treatment of BEVs, the interaction between consumer and producer decisions including decisions between cars and light trucks, and the capability to consider a wider range of GHG program options. The OMEGA2 model is currently under peer review and we expect to make the results public early next year.

As previously noted, we are using the version of the CCEMS docketed by NHTSA in support of the SAFE FRM. CCEMS itself has been extensively documented by NHTSA in support of the SAFE FRM and the documentation used there is applicable to the analysis presented here.[7] Table 4-1 shows changes that were made to CCEMS for the NPRM analysis. In addition, the following changes have been made to the inputs for this analysis for the final rule (see Table 4-2).

For this FRM analysis, EPA is using the MY 2020 base year fleet developed by NHTSA for their recent NPRM and allowing the model to determine the future fleet based on the consumer choice model and scrappage models.[7,a] As such, we have not changed the data contained within the market file (the base year fleet) from what was used in NHTSA's recent NPRM other than as described in Table 4-2 and to split the market file into separate framework-OEM and non-framework-OEM fleets for some model runs to account for the impacts of the California Framework Agreement.[8] Note that the scrappage model received many negative comments following the SAFE NPRM, but the FRM version of the model incorporated changes such that it no longer generates the sales and VMT results of the NPRM version which was described by commenters during the SAFE rule as being inconsistent with economic theory.[9] The changes incorporated are also consistent with recommendations of the EPA Science Advisory Board.[10]

As mentioned, for some model runs, including the No Action case, we have split the fleet in two, one fleet consisting of California Framework manufacturers and the other consisting of the non-Framework manufacturers. This was necessary since, for years that we are modeling previous to the MY 2023 start of this program, we modeled the Framework manufacturers meeting the more stringent Framework emission targets (as set in the scenarios file) while having access to the additional advanced technology incentive multipliers of the Framework. We modeled the Non-Framework-OEMs meeting less stringent (SAFE) standards while having access to no advanced technology multipliers. For such model runs, a post-processing step was necessary to properly sales-weight the two sets of model outputs into a single fleet of results. This post-processing tool is in the docket for this rule.[11]

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[a] See Chapter 8.1 for discussion of modeling of vehicle sales, as well as references to reviews of the literature that EPA has conducted.

Table 4-1: Changes made to SAFE FRM CCEMS Inputs for NPRM Model Runs

Input file	Changes
Parameters file	Global social cost of GHG $/ton values used in place of domestic values (see Chapter 3.3). Inclusion of global social cost of methane (CH_4) and nitrous oxide (N_2O) $/ton values (see Chapter 3.3). Updated $PM_{2.5}$ cost factors (benefit per ton values, see Chapter 7) Rebound effect of -0.10 rather than -0.20 (see Chapter 3.1). AEO2021 fuel prices (expressed in 2018 dollars) rather than AEO2019. Update energy security cost per gallon factors (see Chapter 3.2). Congestion cost factors of 6.34/6.34/5.66 (car/van-SUV/truck) cents/mile rather than 15.4/15/4/13.75 (see Chapter 3.4). Discounting values to calendar year 2021 rather than calendar year 2019. The following fuel import and refining inputs have been changed based on AEO2021 (see Chapter 3.2): Share of fuel savings leading to lower fuel imports: Gasoline 7%; E85 19%; Diesel 7% rather than 50%; 7.5%; 50% Share of fuel savings leading to reduced domestic fuel refining: Gasoline 93%; E85 25.1%; Diesel 93% rather than 50%; 7.5%; 50% Share of reduced domestic refining from domestic crude: Gasoline 9%; E85 2.4%; Diesel 9% rather than 10%; 1.5%; 10% Share of reduced domestic refining from imported crude: Gasoline 91%; E85 24.6%; Diesel 91% rather than 90%; 13.5%; 90%
Technology file	High Compression Ratio level 2 (HCR2, sometimes referred to as Atkinson level 2) technology allowance set to TRUE for all engines beginning in 2018 (see Chapter 2).
Market file	On the Engines sheet, we allow HCR1 and HCR2 technology on all 6-cylinder and smaller engines rather than allowing it on no engines (see Chapter 2). Change the off-cycle credit values on the Credits and Adjustments sheet to 15 grams/mile for 2020 through 2026 (for the CARB-OEM framework) or to 15 gram/mile for 2023 through 2026 (for the proposed option) depending on the model run.

Table 4-2: Changes made to EPA NPRM CCEMS Inputs for Final Rule Model Runs

Input file	Changes *
Parameters file	Updated Gross Domestic Product, Number of Households, VMT growth rates and Historic Fleet data consistent with updated projections from EIA (insert AEO version). Updated energy security cost per gallon factors (see preamble Section VII.F). Updated benefit per ton values and unique values for refinery and electricity generating unit benefits (see preamble Section V). Updated tailpipe and upstream emission factors consistent with (insert updated model runs)
Technology file	High compression ratio level 2 (HCR2, sometimes referred to as Atkinson cycle) technology allowance set to FALSE thereby making this technology unavailable. BEV200 phase-in start year set to the same year as the new market file fleet (see below) which, given the low year-over-year phase-in cap allows for low penetration of BEV200 technology in favor of BEV300 technology. Battery cost was reduced by about 25 percent (see preamble Section III.A); battery cost learning is also held constant (i.e., no further learning) beyond the 2029 model year (see RIA 2.3.4 and 4.1.3).
Market file	The market file has been completely updated to reflect the MY 2020 fleet rather than the MY 2017 fleet used in the SAFE FRM and the EPA proposed rule. This was done by making use of the market file developed by NHTSA in support of their recent CAFE NPRM (cite). Because the market files are slightly different between the version of CCEMS we are using and the version used by NHTSA, the files are not identical. However, the data are the same with the following exceptions: - We have conducted all model runs using EPA Multiplier Mode 2 rather than Mode 1 as used in the SAFE FRM and our NPRM. - We have used projected off-cycle credits as developed by NHTSA in support of their recent CAFE NRPM rather than modeling all manufacturers as making use of the maximum allowable off-cycle credits (see RIA 4.1.1.1). - We have updated the credit banks to incorporate more up-to-date information from manufacturer certification and compliance data.
Scenarios file	The off-cycle credit cap has been set to 10 g/mi even in scenarios and years for which 15 g/mi are available. In addition, the off-cycle credit cost is set to $0 and is then post-processed back into the costs calculated within CCEMS itself. See RIA 4.1.1.1 for more detail on why this was done and the cost per credit that we are using in this final rule.
Runtime settings	At runtime (in the CCEMS graphical user interface), the "Price Elasticity Multiplier" is now set to -0.40 rather than the value of -1.00 used in the NPRM analysis.
Notes: *As noted, we are now using a MY 2020 baseline fleet rather than a MY 2017 baseline fleet. However, since some date-based data used by the model is hardcoded in the model code, and because we did not want to change the model code for consistency with the NPRM, we have had to adjust any date-related input data accordingly. Therefore, the input files we are using have in them headings and date-related identifiers reflecting a MY 2017-based analysis but the data in the files have been adjusted by 3 years to reflect the fact that anything noted as 2017 is actually 2020. This is most easily understood with respect to the Scenarios input file which specifies the standards in a year-by-year format. Due to this need to “shift years”, the standards for MY 2023 through MY 2026 are actually entered in the columns noted as 2020 through 2023. Importantly, in post-processing of model results, the “year-shift” is corrected back to reflect the actual years.	

Our primary model runs consist of a “no action” case and an “action” case. The results, or impact of our proposed standards, are measured relative to the no action case. Our no action case consists of the Framework manufacturers (roughly 28 percent of fleet sales) meeting the framework while NonFW-OEMs (roughly 72 percent of fleet sales) meet the SAFE FRM standards. Our action case consists of the whole fleet meeting our standards for model years 2023 and later. Throughout this discussion, our no action case refers to this Framework/Non-Framework manufacturer compliance split. We provide more detail behind some of the changes made to the model inputs since our proposed rule in the following section (4.1.1).

Importantly, CCEMS includes refresh and redesign schedules for all vehicles included in the MY 2020 base fleet. These schedules are designed to capture the real-world constraints associated with technology adoption and lead time. Some technologies can be added, or improved, during a refresh event, while others require a redesign event. All of the electrification technologies, including start-stop, hybridization and any form of plug-in electrification, require a redesign event. When these refresh and redesign events are projected to occur impacts the ability of manufacturers to comply with new standards and also highlights the importance of flexibilities, especially averaging, banking and trading of credits, which allow manufacturers to implement technologies on regular refresh/design schedules to minimize costs. The refresh and redesign schedules we are using are consistent with those used by NHTSA in their recent CAFE NPRM.[12] The MY 2020 base fleet sales and shares of vehicles available for refresh and redesign are shown in Table 4-3.

Table 4-3 Vehicle Sales Available for Refresh and Redesign

Model Year	Refresh		Redesign	
	Sales	Share	Sales	Share
2021	1,783,285	13%	1,642,353	12%
2022	3,818,816	28%	2,572,865	19%
2023	2,288,923	17%	1,308,090	10%
2024	2,396,924	18%	3,422,953	25%
2025	2,084,892	15%	1,643,477	12%
2026	1,291,583	10%	2,379,932	18%

Lastly, to calculate the full program costs, benefits and net benefits, EPA has developed and made use of an aforementioned post-processing tool.[13] For many benefit-cost metrics, the post-processing tool follows the calculation approach employed within the CCEMS model. For example, costs associated with application of technology, foregone consumer sales surplus, congestion, noise, fatalities and non-fatal crashes are all handled within the CCEMS model and are taken "as-is" in the post-processing tool and transferred through to the final cost-benefit analysis. However, the calculation of emissions benefits is handled entirely within the post-processing tool by applying EPA's preferred $/ton benefit values (for both criteria air pollutants (CAP) and GHGs) and discounting those values exclusively at their internally consistent discount rates. In other words, the social cost of GHG $/ton values are generated using discount rates equal to 2.5 percent, 3 percent and 5 percent. Each of those streams of benefit values will always be discounted, whenever discounting is employed (for net present and/or annualized valuations) using the internally consistent discount rate. CCEMS uses this same approach. However, CCEMS can calculate only a single GHG valuation in each run of the model. As such, to monetize 4 GHG streams (2.5 percent, 3 percent, 5 percent, 3 percent-95th percentile) would require 4 separate runs of the model despite the fact that the tons do not differ between runs. Therefore, EPA has chosen to post-process the results such that all 4 streams could be monetized without re-running the full CCEMS. The post-processing tool also allows for valuation of upstream CAP benefits separately from tailpipe CAP benefits which the SAFE FRM version of CCEMS does not allow.

4.1.1 Changes made to the Model Inputs since the Proposed Rule

4.1.1.1 Off-Cycle Credit Cost and changes since the Proposed Rule

We have updated the cost of off-cycle credits compared to the analysis for the NPRM. In the NPRM, we used the off-cycle credit costs developed by NHTSA in support of the SAFE FRM. Those costs are shown in Table 4-4.

Table 4-4: Cost per Off-Cycle Credit used in the NPRM (2018 dollars)

	2020	2021	2022	2023	2024	2025	2026
$/gram/mile	83.79	82.21	81.16	79.58	78.52	77.47	76.31

CCEMS applies these costs on a $/gram/mile basis based on the credits entered in the market input file. As a result, a MY 2026 vehicle adding 15 grams of off-cycle credits (as would have been the case in our model runs for the proposed rule) would be adding $1,145 dollars in off-cycle technology (15 x 76.31). In the no action case, most vehicles would have added just 10 grams/mile of off-cycle credit technology for a cost of $763. Therefore, the incremental costs between the no action and action case vehicles would have automatically been $382 ($1,145 - $763). Both the cost of these credits and the automatic application of those credits with different levels of credits in different scenarios was considered inappropriate.

To address this, we ran CCEMS with different levels of off-cycle credit applied (again, automatically) but with zero cost. For the curve coefficients used, we got the results shown in Table 4-5.

Table 4-5: Cost per Vehicle relative to No Action at different levels of Zero-Cost Off-cycle Credit (2018 dollars)

Off-cycle credits	2021	2022	2023	2024	2025	2026	2027
0 g/mi	$90	$260	$500	$750	$820	$1,030	$1,110
5 g/mi	$30	$90	$310	$560	$710	$890	$970
10/g/mi	-$20	-$30	$190	$390	$540	$690	$760
15 g/mi	-$20	-$40	$180	$390	$540	$700	$760

As expected, the costs per vehicle are lower with increasing levels of off-cycle credit. This helps illustrate the value of off-cycle credits relative to other available technologies. We can look at these data another way, by looking at the incremental costs for the different ranges of off-cycle credits, as shown in Table 4-6.

Table 4-6: Incremental Off-cycle Credit Cost ($/gram) for Different Levels of Off-cycle Credit (2018 dollars)

Off-cycle credits	2021	2022	2023	2024	2025	2026	2027
0 to 5 g/mi	$12	$34	$38	$38	$22	$28	$28
5 to 10 g/mi	$11	$29	$24	$34	$34	$40	$42
10 to 15 g/mi	$7	$20	$2	$0	$0	-$2	$0

In other words, with 15 grams/mile of free off-cycle credits, the cost per vehicle is essentially the same as with 10 grams/mile of free off-cycle credits. As a result, the cost/gram of those 5 additional credits is suggested to be essentially $0. Looked at another way, the MY 2026 cost when no off-cycle credits are made available was $1,030. With 10 grams of free off-cycle credits available, the costs reduced to $690. This suggests that the value of the 10 grams of off-cycle credits were $34/gram ($1030 - $690 = $340; $340/10=$34). Some of those credits were available at $28/gram in the 0 to 5 g/mile increment and others were available at $40/gram in the 5 to 10 g/mile increment (see Table 4-6 for MY 2026). Given that the largest incremental cost shown is $42, and the desire to be conservative, we have used a value of $42/grams/mile for off-cycle credits. Importantly, since identical off-cycle credits are projected in all scenarios in our modeling, the incremental costs between scenarios is not impacted by this valuation of off-cycle credits.

4.1.1.2 Battery Costs and Changes since the Proposed Rule

In the proposed rule we used the battery costs and battery cost learning curve used by NHTSA in the SAFE FRM. This learning curve is part of the technologies input file. As described in more detail in Section 2.3.4, we wanted to adjust the battery costs applied in CCEMS to better represent cost savings represented by recent developments, such as increased battery manufacturing capacity and economies of scale, cathode chemistries with reduced cobalt content, and also cell capacities and pack topologies that are more consistent with emerging dedicated BEV platforms (see Chapter 2.3.4). However, those costs are integrated into the executable file for the model and thus battery pack costs that are used by the model cannot be modified without recompiling the code, a step we did not want to make since it might imply that the model code was different and not just the battery cost input file.

An alternative approach was to modify the placement of the learning curve values that are applied to the battery pack cost inputs as those inputs are entered into the model. By shifting the battery cost learning curves, we could, in effect, adjust the battery costs prior to initiation of the compliance modeling.

First, we conducted an assessment to determine by how much the costs should be reduced. EPA reviewed the battery costs used in the SAFE rulemaking, which had been carried over to the analysis for EPA's August 2021 Notice of Proposed Rulemaking (NPRM). We considered the inputs that had previously been used to derive the costs for the SAFE rulemaking, and compared those costs to the costs that EPA had derived in previous and ongoing analyses. The costs were also compared to the current and expected future costs of batteries as widely reported in the trade and academic literature. We concluded that the battery costs used in the proposal were broadly higher than indicated by this evidence, and that the likely effect of using an updated set of assumptions would produce projected battery costs significantly lower than those proposed and more in agreement with emerging consensus on the level and direction of battery costs in the industry.

In the SAFE FRM, the agencies used the Argonne National Laboratory BatPaC 3.1 model as a basis for developing battery costs, and chose a set of inputs that included an annual production volume of 25,000 packs, a BEV battery chemistry of NMC622-G, and a modified cell yield rate that was lower than the recommended value provided by the authors of BatPaC. Cell capacities and pack topologies can also have a strong influence on pack cost, and we noted that several OEMs have begun production of dedicated BEV vehicle platforms that use larger, standardized cell and module designs.

In previous analyses, EPA estimated battery pack costs using annual production volumes of 50,000, 125,000, 250,000 and 450,000 packs per year. Given the scale and size of battery plants in operation now and planned for the future, and given the increasing use of relatively standardized cells that can be used in more than one capacity of pack, we believe that an annual volume of 125,000 units is more appropriate to represent the manufacturing capacity of battery plants over the timeframe covered by the analysis for the Final Rule. Given increased use of low-cobalt NMC811-G chemistry, and ongoing pressure to reduce battery costs and reliance on imported cobalt, we believe that it is now a more appropriate choice for BEV battery chemistry. We do not find evidence that the cell yield rate should be modified from the BatPaC default value. We also find that cell capacities and pack topologies should be chosen to be consistent with emerging dedicated BEV platforms such as for example, the GM Ultium platform, the Volkswagen MEB platform and the Hyundai e-GMP platform which all use relatively large capacity cells of relatively fixed Ampere-hour capacities in well-defined pack topologies and are all based upon vehicle platforms shared among multiple vehicle models with the underlying platforms intended for high-volume vehicle production (i.e., approximately 125,000 vehicles per year or more). Based on an assessment of the effect of using these updated inputs to the BatPaC 4.0 model in place of those used in the SAFE rulemaking, we found technical justification for reducing battery costs by approximately 25 percent, as described below.

In the SAFE final rulemaking analysis, NHTSA cited an example 60 kWh BEV battery and stated a direct manufacturing cost at $178/kWh in 2020 and $141 in 2025, based on BatPaC outputs using the inputs they had selected. Cost inputs to the CCEMS model are considered RPE-inclusive costs, and thus direct manufacturing costs derived for the analysis are to be multiplied by the 1.5 RPE multiplier before being input to the model. The cost for this hypothetical $178/kWh battery would thus be input to the CCEMS model as $267/kWh, an RPE-inclusive cost applicable to 2020. Similarly for 2025, this $141/kWh battery (in 2025) would be input to the CCEMS model as $212/kWh, an RPE-inclusive cost for 2025.

Current trends and broad consensus on the state and direction of battery costs indicate that the direct manufacturing cost of a 60 kWh BEV battery was likely lower than $178/kWh in 2020 and will likely be lower than $141/kWh in 2025. Using the updated BatPaC 4.0 and using the input assumptions described above, BatPaC indicates a cost of about $129/kWh, or an RPE-inclusive cost of $194/kWh. Because the previous RPE-inclusive cost for this battery was $267/kWh, this suggests that its cost could be reduced by about 25 percent. Because the indicated change resulted primarily from factors that would affect batteries across the analysis in a roughly similar manner (production volume, lower-cobalt chemistry, cell yield, and larger cell capacity) we concluded that it was reasonable to apply a similar battery cost reduction across the analysis.

As a means to adjust the battery cost inputs to the CCEMS model, we adjusted the battery cost learning curve such that the curve now applies a learning factor of 1.0 six years earlier than previously, which in effect results in battery cost inputs to the CCEMS model being reduced by about 24 percent, consistent with the results of our updated technical assessment. This does not represent a reconsideration of learning inputs but only acts as a mechanism to apply a correction factor to the battery costs being input to the CCEMS model.

For the example 60 kWh BEV battery, this results in the cost changes shown in Table 4-7 below.

Table 4-7. Cost Changes for a 60 kWh BEV Battery

	2020	2021	2022	2023	2024	2025	2026
Previous, RPE inclusive	$267	$255	$244	$233	$222	$212	$203
Updated, RPE inclusive	$203	$193	$185	$178	$168	$151	$154
Updated, direct mfg. cost	$135	$129	$123	$119	$112	$107	$102

We note that the resultant direct costs for current and future years within the time frame of the rule are consistent with the preponderance of publicly available reports and projections in the industry, which broadly project BEV battery costs reaching approximately $100/kWh at the pack level by mid-decade. For example, the National Academies of Sciences (NAS) Phase 3 Report projects pack-level costs between $90-$115/kWh by 2025.[14] For the year 2020, the updated estimate of $135/kWh closely corresponds to the volume-averaged OEM price of $137/kWh reported for that year by the Bloomberg New Energy Finance (BNEF) 2020 Battery Price Survey.[15]

We also considered the effect of this reduction on the projected battery costs for future years beyond the time frame of the rule. Applying the existing learning curve to the downward adjusted costs past the time frame of the rule would produce costs gradually declining to below $80 per kWh (for an example 60 kWh battery) in the mid-2030s and to about $75/kWh by the mid-2040s.

At this time, EPA is uncertain about the potential for battery costs to reach those levels due in part to uncertainties about the effect of increased demand for critical minerals and other factors, which we also received comment on, and also because our current battery modeling tools such as BatPaC 4.0 are unable to generate costs at these levels using inputs that can reasonably be validated. Moreover, the concept of a learning curve normally applies to "learning by doing," that is, it represents savings that result from incremental improvements in manufacturing processes or small design changes for a specific form of a technology and is not intended to represent savings that might result from a step change to a different form of the technology. Many forecasts that anticipate continued lowering of battery costs below a level that can be technically demonstrated today incorporate the assumption that step changes to the form of the battery cell, for example, a shift to lithium-metal anodes or solid-state construction, will make the projected costs possible. Although EPA believes that cost reductions from these new forms of battery technology are likely to occur in the future, EPA is uncertain if it is appropriate to account for them by applying a learning curve to costs applicable to the current form of the technology. Significantly, these new forms of cell technology have not yet been demonstrated in large volume automotive applications, making it difficult to estimate their cost reduction potential with a reasonable degree of certainty.

Even though application of a learning curve to a specific technology can be said to assume unspecified improvements in manufacturing efficiencies or small design changes, the future costs projected by the curve should still be capable of being validated by reasonable assumptions for these efficiencies and changes, within reasonable technical boundaries of the specific technology. Using the current battery cost modeling tools at our disposal, and using a set of reasonable assumptions applicable to the prevailing form of lithium-ion chemistries, it is possible to reasonably validate the potential for costs to be reduced to approximately $90 per kWh for a 60 kWh battery. Due to the widely acknowledged uncertainty of quantitatively projecting declines in battery costs far into the future, and particularly in the context of the downwardly adjusted battery costs, we chose to flatten the rate of learning past 2029 so as to prevent future costs from declining below $90 per kWh for a 60 kWh battery, a level that we can currently technically validate and which corresponds to the more optimistic end of the NAS estimate for 2025. Although EPA believes that this reflects an appropriate technical application of a learning curve, it does not represent the potential for cost reductions from step changes to the technology that may occur in the future. Therefore, in years beyond the time frame of the rule, the adjusted costs are conservative with respect to the forecasts of BNEF ($58 in 2030) and NAS ($65-$80 by 2030), both of which we believe would require some of their projected cost reduction to result from significant changes to the technology that have not yet been demonstrated.

With regard to the reliability of battery cost forecasts beyond 2030, NAS on p. 5-139 of the Phase 3 report states in the context of their own analysis, "as there is higher uncertainty related to battery technology past 2030, rigorous cost estimates past this point are not attempted."[16] We agree with the implication that battery cost estimates past 2030 are by their nature highly uncertain and difficult to quantify in a rigorous way. While the NAS Phase 3 report did offer a forecast of $65 to $80 per kWh for 2030, we also note that this forecast appears to be derived qualitatively from a number of forecasts gathered from the literature, that vary considerably in their technical bases and assumptions, and are not focused on recently emergent issues such as production capacity and mineral demand. Significantly, the list of cited sources omits a 2019 MIT study that explicitly considered the effect of mineral costs on the potential for future reductions in battery cost to achieve the levels forecast by some of the cited studies.[17,18] MIT concludes that the potential for cost reduction is likely to be limited by the cost of raw materials and may plateau in a range closer to $100 per kWh for the most widely used family of lithium-ion chemistries. Our choice of $90 per kWh as a lower limit is thus within the range bounded by the estimates of NAS and MIT.

It is also important to note that the costs referenced here pertain only to an example 60 kWh battery. Many EVs are expected to have larger batteries, with 75 to 100 kWh already common in the market. Battery cost on a dollar per kWh basis tends to decline as battery packs get larger in capacity. Thus, the equivalent lower limit in our analysis for a 75 kWh or 100 kWh battery that is presented to the CCEMS model would be less than $90 per kWh in 2029 and later.

As already noted in Section 2.3.4 of this RIA, we believe that holding learning constant after 2029 is likely a conservative assumption, as we continue to expect that continued learning and/or cost reductions resulting from a change to solid-state or lithium-metal technology or other developments will occur beyond 2029 but there is uncertainty at this point on what the appropriate rate of cost reduction resulting from these sources would be. Thus, our battery cost estimates beyond 2029 in this final rulemaking may be conservatively high.

In consultation with battery experts at the Department of Energy Vehicle Technologies Office (DOE VTO), we jointly agreed that it is appropriate to be conservative regarding estimates of future battery costs, including the use of the lower limit as an interim step to represent current uncertainty about the ability for the cost of current-generation technology to learn down in the face of uncertain future material costs. Although DOE often makes estimates of future battery costs that are nominally below this limit, these estimates are meant to guide research and are often targets or “stretch goals,” not necessarily predictions, as they anticipate future technical progress which is difficult to predict. For example, the US Advanced Battery Consortium (USABC) has set a long-term goal of $75 per kWh, which serves as a target that guides ongoing research by representing a goal that is qualitatively regarded as achievable although not yet achieved. At the same time, these targets reflect significant promise for future cost reductions by means of several potential pathways. These include, among others, reduced use or elimination of critical and expensive materials such as cobalt and nickel, lower material costs through improved efficiencies and economies of scale, increased energy density through use of next-generation materials like silicon or lithium metal anodes and higher energy cathodes (resulting in less material needed per kWh), and more effective material use and recycling practices within the factory.

DOE actively conducts research and target setting activities that could improve EPA’s ability to better quantify future battery costs in a subsequent rulemaking. DOE VTO currently funds cost modeling at Argonne National Laboratory, including near-term improvements to the BatPaC model that will model advanced cell formats, pack formats, and chemistries, including next-generation materials. In battery research, DOE spends about $10-15 million per year on silicon-based technologies and cells, $10-15 million per year on lithium-metal technologies, $10-15 million per year on low- or no-cobalt cathodes, and $7-12 million per year on battery recycling technologies. The Infrastructure Investment and Jobs Act will provide $6 billion in federal funding to develop a domestic lithium-ion energy storage supply chain and an additional $320 million on recycling and secondary use activities.

EPA continues to study the potential for cost reductions in batteries to occur during and after the time frame of the rule. For example, we expect that the aforementioned updates to the ANL BatPaC model, as well as collection of emerging data on forecasts for future mineral prices and production capacity, will make it possible to characterize the continued declines in battery costs that we continue to believe will occur after 2029, as well as trends in costs in the nearer term. These developments are likely to improve our ability to quantify the potential for cost reductions past 2029, in place of the lower limit we have assumed for this analysis, and we plan to incorporate this information in the subsequent rulemaking for MYs 2027 and beyond.

4.1.1.3 Restricting HCR2 Technology from the Available Technologies

The HCR2 technology in this version of CCEMS would require a level cylinder deactivation technology, dynamic cylinder deactivation, that has not yet been added to Atkinson Cycle Engines either with or without cooled EGR.[b] HCR1 technologies reflect the effectiveness of Atkinson Cycle engines with either cooled EGR or fixed cylinder deactivation (however, not both technologies in combination) and thus also represent a number of high-volume ICE applications from Mazda, Toyota and Hyundai. The additional step to HCR2 reflected a level of ICE effectiveness that, while technologically feasible, is not yet within the light-duty vehicle

[b] Dynamic cylinder deactivation allows any number of cylinders to be deactivated on a cycle-resolved basis. Fixed cylinder deactivation deactivation deactivates a fixed number of cylinders under certain operating conditions (e.g., deactivating 2 out of 4 cylinders). Dynamic cylinder deactivation is currently used by GM in pickup truck and full-size SUV applications, but has not yet been used in combination with Atkinson Cycle in a production application. Fixed cylinder deactivation is now standard on Mazda implementations of Atkinson Cycle.

fleet, and that we also do not anticipate seeing until the later years of this final rule (e.g., MYs 2025-2026). For the final rule, we chose a more conservative approach. We have chosen to set its availability to FALSE in the technologies input file for the Final Rule and to add a sensitivity analysis on HCR2 for MYs 2025 and later. This allows us to show two different compliance paths - one with and one without HCR2. This has two impacts on the results of the CCEMS analysis for the final rule:

- Slightly higher technology costs (less than $15 per vehicle) since a highly cost-effective gasoline technology is not available
- Slightly higher electrified technology penetrations (BISG, HEV, PHEV, BEV) since more electrification is required than would otherwise be the case, and because vehicle electrification costs have been reduced in the final rule due to updated (lower) battery costs.

For more information on HCR technologies, please refer to Chapter 2.3.2. For results of the sensitivity analysis using HCR2, please refer to Chapter 4.1.5.1.

4.1.1.4 Shifting of Input File Years due to the Updated Baseline Fleet

As noted in Table 4-2, we have updated the baseline fleet to reflect the MY 2020 fleet rather than the MY 2017 fleet used in the NPRM. However, due to hardcoded entries in the CCEMS code, we had to create an offset within the model to allow use of the MY 2020 fleet instead of the MY 2017 fleet. To do this, every year-based entry in each of the model input files had to be adjusted by 3 years such that any data were entered in an input column shifted by 3 years. For example, in the scenarios input file, standard curve coefficients for MYs 2023 through 2026 are entered in columns with the headers 2020 through 2023. Similarly, banked credits in the market input file are entered in columns headed by 2012 through 2016 even though those banked credits are actually 2015 through 2019 vintage credits. This was also done to refresh and redesign schedules within the market file and for all of the technology costs and learning curve factors in the technologies file. Importantly, in the post-processing tool used to recombine Framework and non-Framework manufacturer model runs, the years are shifted back to their proper timing such that, while the direct model output files present data shifted by 3 years, the post-processed files reflect actual calendar and model year data.

4.1.2 <u>GHG Targets and Compliance Levels</u>

4.1.2.1 Final Standards

The final standard curve coefficients are presented in Preamble Section II.A.2. Here we present the fleet targets for each manufacturer. Figure 4-1 depicts the fleet targets of the SAFE FRM and today’s final standards. Also shown are the targets from the 2012 FRM and the proposed standards from the August 2021 NPRM (Proposal). As can be seen, the final standards move from the SAFE FRM in the same manner as the Proposal in MYs 2022 and 2023. It then achieves greater stringency than the Proposal and surpasses the 2012 FRM targets by MY 2026.

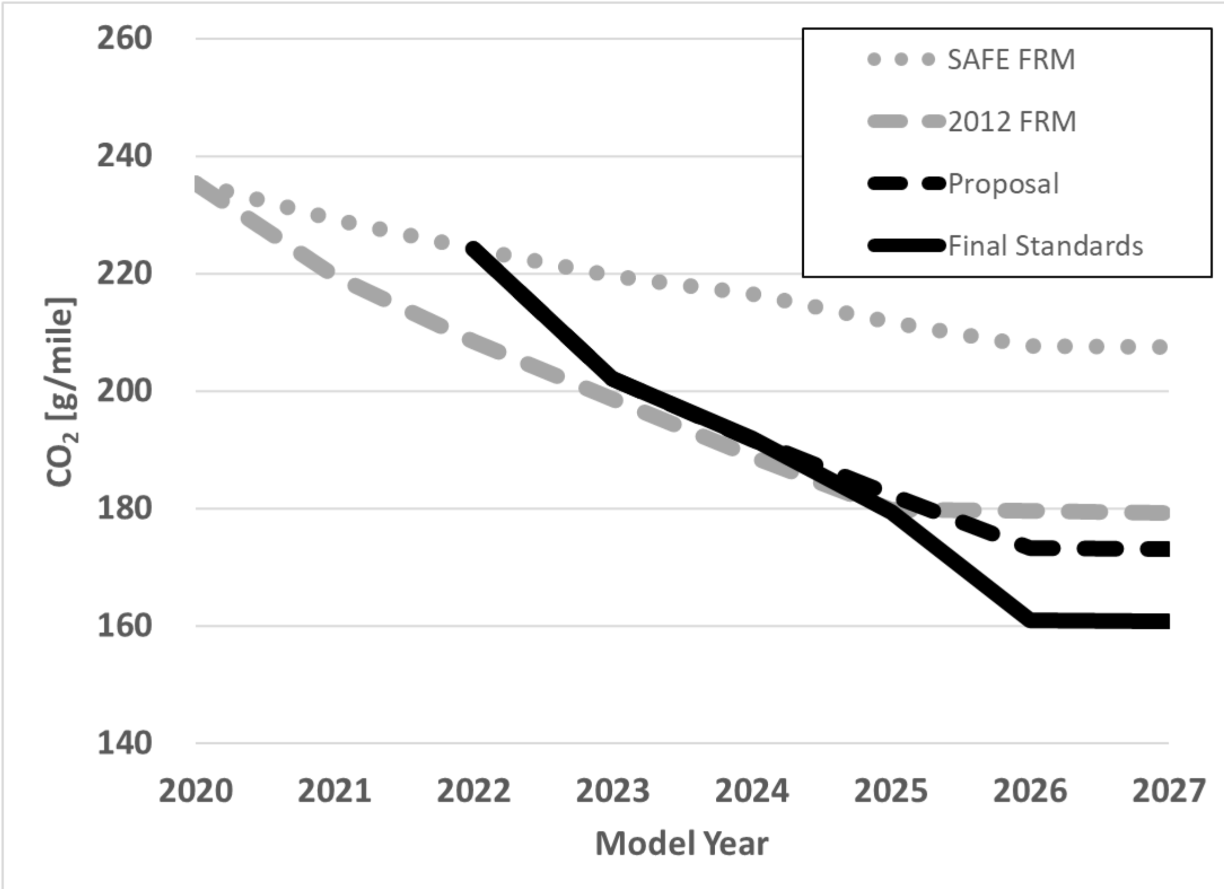

Figure 4-1: Final Fleet-Wide CO_2-Equivalent g/mi Compliance Targets (solid black line), Compared to 2012 FRM, SAFE Rule, and Proposal.

These targets are dependent on each manufacturer's car and truck fleets and their sales weighted footprints. As such, each manufacturer has a set of targets unique to them. Those targets are shown by manufacturer for MYs 2023 through 2026 in Table 4-8 for cars, Table 4-9 for trucks, and Table 4-10 for the combined fleet.

Table 4-8: Car Targets (CO_2 gram/mile)

Manufacturer	2023	2024	2025	2026
BMW	169	161	152	135
Daimler	174	166	156	139
FCA	176	168	158	140
Ford	170	162	153	136
General Motors	163	155	147	130
Honda	164	156	147	130
Hyundai Kia-H	165	157	148	131
Hyundai Kia-K	163	155	146	129
JLR	171	163	154	136
Mazda	163	155	147	130
Mitsubishi	153	145	137	120
Nissan	166	158	149	132
Subaru	159	152	143	126
Tesla	179	171	161	144
Toyota	164	156	147	130
Volvo	176	168	158	141
VWA	164	156	148	131
TOTAL	166	158	149	132

Table 4-9: Light Truck Targets (CO_2 gram/mile)

Manufacturer	2023	2024	2025	2026
BMW	227	216	201	182
Daimler	227	216	201	182
FCA	241	229	213	193
Ford	249	237	220	200
General Motors	252	240	223	203
Honda	216	205	191	172
Hyundai Kia-H	231	219	204	184
Hyundai Kia-K	218	207	193	174
JLR	223	212	197	177
Mazda	206	196	182	163
Mitsubishi	194	184	171	153
Nissan	221	210	195	176
Subaru	202	192	178	160
Tesla	236	224	209	189
Toyota	227	215	201	181
Volvo	222	211	196	176
VWA	214	203	189	170
TOTAL	234	222	207	187

Table 4-10: Sales Weighted Fleet Targets (CO_2 gram/mile)

Manufacturer	2023	2024	2025	2026
BMW	190	181	170	152
Daimler	200	190	177	159
FCA	231	219	204	185
Ford	228	217	202	183
General Motors	221	210	196	177
Honda	186	176	165	147
Hyundai Kia-H	171	163	153	136
Hyundai Kia-K	182	172	161	144
JLR	220	209	195	175
Mazda	184	175	164	146
Mitsubishi	174	165	155	137
Nissan	181	172	162	144
Subaru	191	182	169	151
Tesla	180	172	162	145
Toyota	191	181	169	151
Volvo	210	200	186	167
VWA	193	183	171	153
TOTAL	202	192	179	161

The actual achieved $CO_{2\text{-equivalent}}$ (CO_2e) levels, which include the effect of credit programs on compliance, are shown in Table 4-11 for cars, Table 4-12 for trucks, and Table 4-13 for the combined fleets.

Table 4-11: Car Achieved (CO_2e gram/mile)

Manufacturer	2023	2024	2025	2026
BMW	192	173	138	121
Daimler	171	150	158	155
FCA	160	152	163	149
Ford	158	157	158	146
General Motors	163	158	158	153
Honda	163	153	147	138
Hyundai Kia-H	160	149	134	132
Hyundai Kia-K	166	155	143	142
JLR	224	188	189	189
Mazda	166	146	146	145
Mitsubishi	186	185	127	126
Nissan	170	157	132	132
Subaru	201	189	188	168
Tesla	-10	-10	-10	-10
Toyota	161	138	134	132
Volvo	207	204	198	181
VWA	165	153	156	127
TOTAL	160	148	140	134

Table 4-12: Light Truck Achieved (CO_2e gram/mile)

Manufacturer	2023	2024	2025	2026
BMW	197	197	203	203
Daimler	229	229	193	84
FCA	215	212	210	189
Ford	250	222	222	192
General Motors	265	238	217	193
Honda	214	167	163	163
Hyundai Kia-H	268	267	266	127
Hyundai Kia-K	209	188	195	194
JLR	214	203	179	146
Mazda	203	202	177	118
Mitsubishi	227	226	130	130
Nissan	205	200	195	181
Subaru	186	175	167	167
Tesla	-9	-9	-9	-9
Toyota	236	208	216	176
Volvo	158	156	162	161
VWA	213	203	171	147
TOTAL	230	211	203	178

Table 4-13: Sales Weighted Fleet Achieved (CO_2e gram/mile)

Manufacturer	2023	2024	2025	2026
BMW	194	182	162	151
Daimler	199	188	175	122
FCA	206	202	203	183
Ford	225	205	205	180
General Motors	230	210	196	179
Honda	184	159	153	148
Hyundai Kia-H	171	160	147	131
Hyundai Kia-K	180	166	160	159
JLR	215	203	179	149
Mazda	184	173	161	132
Mitsubishi	207	206	128	128
Nissan	180	169	150	145
Subaru	190	178	173	168
Tesla	-10	-10	-10	-10
Toyota	192	167	168	150
Volvo	170	169	172	166
VWA	193	182	164	139
TOTAL	197	181	173	157

Note that the values shown in Table 4-11 through Table 4-13 are modeled tailpipe certification values considering use of A/C leakage credits and other off-cycle credits apart from A/C leakage. This explains the negative 10 grams/mile CO_{2e} shown for Tesla cars. That value reflects 5 grams/mile of A/C efficiency credits and another 5 grams/mile of off-cycle credits. These are simply the input values for Tesla flowing through the model. To date, Tesla has not been a major user of the off-cycle credit program given that they make nothing but BEVs. However, when running the model, we have chosen to apply the off-cycle credit inputs developed by NHTSA in support of their recent NPRM both on the credit side and the cost side for any year in which that credit is available.[19] This differs from the proposed rule where we modeled every manufacturer earning the maximum amount of off-cycle credits available in any given year and under any given scenario (10 grams/mile under the SAFE FRM standards; 15 grams/mile under the proposed standards). However, this added an incremental cost, automatically, of nearly $400 to every vehicle because CCEMS does not have the ability to weigh the application of off-cycle credit technology versus other technologies when making technology application decisions.

4.1.2.2 Alternatives

Table 4-14, Table 4-15 and Table 4-16 show the car, truck and fleet targets, respectively, for the alternatives to the final rule. The alternatives that were analyzed include:

- A less stringent alternative, which were the proposed light-duty GHG standards from the August 2021 NPRM (Proposal)
- A more stringent alternative to the final standards having lower CO_2 standards for MY 2023 and MY 2024 than what has been finalized (Alternative 2 minus 10)
- A graphical representation of the fleet average targets is also shown in Figure 4-2.

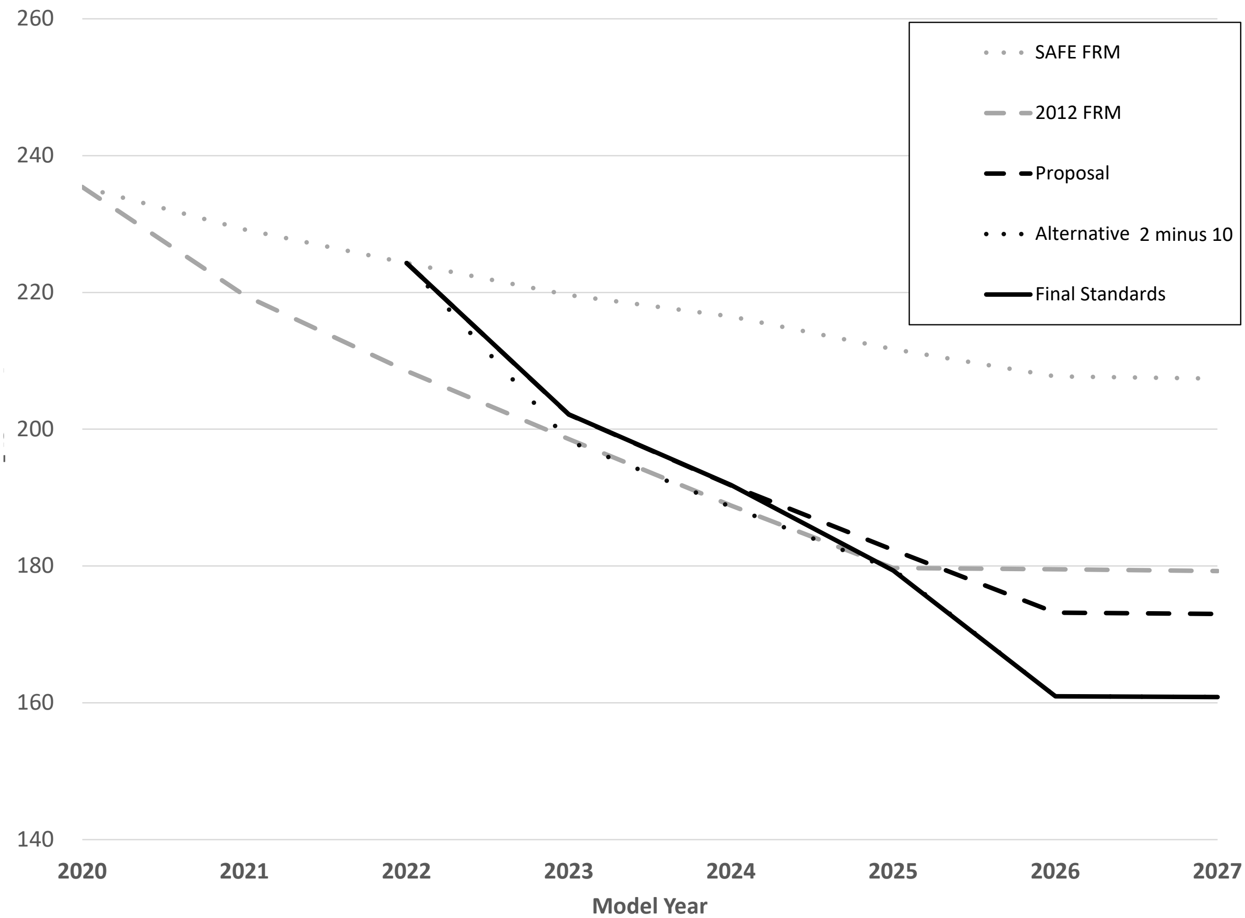

Figure 4-2: Final Rule Fleet Average Targets Compared to the Proposal and Alternative 2 minus 10

The actual achieved CO_2e levels, which include credit programs and their effect on compliance, are shown in Table 4-17, Table 4-18 and Table 4-19 for cars, trucks and the combined fleet.

Table 4-14: Car Targets under the Proposal and Alternative 2 minus 10 Standards (CO_2 gram/mile)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	169	161	153	146	167	159	152	135
Daimler	174	166	157	150	171	164	156	139
FCA	176	168	159	151	172	165	158	140
Ford	170	162	154	147	168	160	153	136
General Motors	163	156	148	141	161	154	147	130
Honda	164	156	149	142	162	155	147	130
Hyundai Kia-H	165	157	150	142	163	156	148	131
Hyundai Kia-K	163	155	147	140	160	153	146	129
JLR	171	163	155	147	168	161	154	136
Mazda	163	155	148	141	161	154	147	130
Mitsubishi	153	145	138	132	150	144	137	120
Nissan	166	158	151	143	164	156	149	132
Subaru	159	152	144	137	157	150	143	126
Tesla	179	171	162	155	177	169	161	144
Toyota	164	156	149	142	162	155	147	130
Volvo	176	168	160	152	174	166	158	141
VWA	164	156	149	142	162	155	148	131
TOTAL	166	158	150	143	164	156	149	132
Notes: Hyundai Kia-H is Hyundai and Hyundai Kia-K is Kia. While these companies are part of Hyundai-Kia, they operate independently for the purpose of compliance with our GHG program.								

Table 4-15: Light Truck Targets under the Proposal and Alternative 2 minus 10 Standards (CO_2 gram/mile)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	227	216	205	195	222	211	201	182
Daimler	227	216	205	195	222	211	201	182
FCA	241	229	217	206	235	224	213	193
Ford	249	237	225	214	243	231	220	200
General Motors	252	240	228	216	246	234	223	203
Honda	216	205	195	185	211	200	191	172
Hyundai Kia-H	231	219	208	198	225	214	204	184
Hyundai Kia-K	218	207	198	188	213	203	193	174
JLR	223	212	201	191	217	207	197	177
Mazda	206	196	186	177	201	191	182	163
Mitsubishi	194	184	175	166	189	180	171	153
Nissan	221	210	200	190	216	205	195	176
Subaru	202	192	182	173	197	187	178	160
Tesla	236	224	213	202	230	219	209	189
Toyota	227	214	205	195	221	211	201	181
Volvo	222	211	200	190	216	206	196	176
VWA	214	203	193	183	209	198	189	170
TOTAL	234	222	211	200	228	217	207	187

Table 4-16: Fleet Targets under the Proposal and Alternative 2 minus 10 Standards (CO_2 gram/mile)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	190	181	172	164	187	178	170	152
Daimler	200	190	180	171	196	187	177	159
FCA	231	219	208	197	225	215	204	185
Ford	228	217	206	196	223	212	202	183
General Motors	221	210	200	189	217	206	196	177
Honda	186	176	168	160	183	174	165	147
Hyundai Kia-H	171	163	155	147	169	162	153	136
Hyundai Kia-K	182	172	164	156	178	170	162	144
JLR	220	209	198	189	214	205	195	175
Mazda	184	175	166	158	181	172	164	146
Mitsubishi	174	165	157	149	170	163	155	137
Nissan	181	172	164	156	179	170	162	144
Subaru	191	182	172	163	187	178	169	151
Tesla	180	172	163	156	178	170	162	145
Toyota	191	180	172	164	187	179	170	151
Volvo	210	200	190	180	205	196	186	167
VWA	193	183	174	165	189	180	171	153
TOTAL	202	192	182	173	198	189	180	161

Table 4-17: Car Targets Achieved under the Proposal and Alternative 2 minus 10 Standards (CO_2e gram/mile)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	191	171	151	135	189	165	145	130
Daimler	174	153	166	163	180	170	169	168
FCA	153	146	163	149	170	162	161	148
Ford	153	153	158	146	156	156	150	138
General Motors	148	143	150	146	132	126	121	116
Honda	164	162	155	145	164	156	147	138
Hyundai Kia-H	160	150	137	135	159	147	141	139
Hyundai Kia-K	165	155	143	142	167	158	152	151
JLR	224	202	202	202	223	196	196	196
Mazda	164	142	146	145	161	144	138	137
Mitsubishi	185	184	132	131	188	187	127	127
Nissan	169	157	142	141	167	154	128	127
Subaru	201	189	188	180	201	189	188	166
Tesla	-10	-10	-10	-10	-10	-10	-10	-10
Toyota	160	139	136	135	161	144	139	136
Volvo	206	203	198	181	209	205	202	184
VWA	167	155	164	145	166	146	142	117
TOTAL	157	147	143	138	156	145	136	131

Table 4-18: Light Truck Targets Achieved under the Proposal and Alternative 2 minus 10 Standards (CO_2e gram/mile)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	198	198	208	208	191	191	191	191
Daimler	227	226	194	161	173	172	167	60
FCA	217	214	216	206	225	222	212	191
Ford	249	222	224	211	245	226	222	193
General Motors	268	246	227	213	270	247	235	209
Honda	217	184	180	180	213	174	163	163
Hyundai Kia-H	270	269	268	196	257	256	255	78
Hyundai Kia-K	214	196	204	203	198	182	181	180
JLR	212	204	194	161	214	199	167	135
Mazda	204	203	177	160	201	200	176	132
Mitsubishi	227	226	158	158	227	226	130	130
Nissan	213	211	208	194	208	205	197	183
Subaru	185	176	170	170	186	173	162	162
Tesla	-9	-9	-9	-9	-9	-9	-9	-9
Toyota	239	209	221	202	226	208	208	168
Volvo	169	168	176	175	171	170	165	163
VWA	209	203	181	172	221	203	164	155
TOTAL	232	215	210	198	229	214	204	179

Table 4-19: Fleet Targets Achieved under the Proposal and Alternative 2 minus 10 Standards (CO_2e gram/mile)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	194	181	172	161	190	174	162	152
Daimler	199	188	179	162	176	171	168	117
FCA	207	203	208	197	216	213	204	184
Ford	224	203	206	193	221	207	203	178
General Motors	226	210	200	189	222	205	195	176
Honda	187	171	165	160	185	164	154	149
Hyundai Kia-H	171	161	149	141	168	157	152	134
Hyundai Kia-K	182	169	163	162	177	166	161	161
JLR	213	204	194	164	214	199	168	139
Mazda	183	171	161	152	181	171	156	134
Mitsubishi	207	206	145	145	208	207	129	128
Nissan	182	172	160	155	179	169	147	143
Subaru	189	179	175	173	190	177	169	163
Tesla	-10	-10	-10	-10	-10	-10	-10	-10
Toyota	193	168	171	162	189	171	167	149
Volvo	179	177	182	176	181	179	174	169
VWA	191	182	174	160	198	179	155	138
TOTAL	197	183	178	169	195	182	172	156

4.1.3 Projected Compliance Costs per Vehicle

4.1.3.1 Final Standards

EPA has performed an updated assessment of the per vehicle costs for manufacturers to meet the revised MY 2023-2026 standards. Importantly, we applied off-cycle credits at the levels entered in the market file as projected by NHTSA in their recent NPRM[20] and applied costs for those credits in a post-processing step at the valuation described in Chapter 4.1.1.1.[21] The car costs per vehicle are shown in Table 4-20, Table 4-21 and Table 4-22 for cars, trucks and the combined fleet, respectively.

Table 4-20: Car Costs/Vehicle Relative to the No Action Scenario (2018 dollars)

Manufacturer	2023	2024	2025	2026
BMW	$8	$112	$840	$762
Daimler	$232	$542	$480	$479
FCA	$253	$212	$158	$329
Ford	$19	$18	$227	$202
General Motors	$577	$546	$651	$669
Honda	$67	$310	$362	$329
Hyundai Kia-H	$92	$132	$756	$790
Hyundai Kia-K	$170	$273	$644	$619
JLR	$26	$619	$581	$547
Mazda	$5	$394	$471	$425
Mitsubishi	$0	$0	$914	$898
Nissan	$228	$327	$1,289	$1,194
Subaru	$18	$18	$17	$209
Tesla	$0	$0	$0	$0
Toyota	$21	$429	$576	$578
Volvo	$0	-$1	$119	$113
VWA	$0	$60	$125	$549
TOTAL	$150	$288	$586	$596

Table 4-21: Light Truck Cost per Vehicle Relative to the No Action Scenario (2018 dollars)

Manufacturer	2023	2024	2025	2026
BMW	$2	$2	$2	$9
Daimler	$35	$34	$725	$3,556
FCA	$1,732	$1,574	$1,465	$1,894
Ford	$39	$477	$428	$754
General Motors	$385	$702	$1,377	$1,746
Honda	$118	$915	$950	$878
Hyundai Kia-H	$45	$44	$43	$4,048
Hyundai Kia-K	$1,194	$1,327	$1,230	$1,144
JLR	$133	$314	$1,321	$1,770
Mazda	$11	$11	$776	$2,500
Mitsubishi	$0	$0	$2,159	$2,028
Nissan	$699	$783	$748	$1,082
Subaru	$2	$27	$57	$57
Tesla	$0	$0	$0	$0
Toyota	$265	$832	$763	$1,537
Volvo	$958	$853	$771	$702
VWA	$0	$125	$461	$856
TOTAL	$485	$732	$909	$1,356

Table 4-22: Fleet Average Cost per Vehicle Relative to the No Action Scenario (2018 dollars)

Manufacturer	2023	2024	2025	2026
BMW	$6	$72	$538	$489
Daimler	$136	$298	$591	$1,925
FCA	$1,502	$1,355	$1,254	$1,639
Ford	$34	$353	$373	$604
General Motors	$452	$648	$1,123	$1,369
Honda	$88	$563	$606	$557
Hyundai Kia-H	$87	$123	$688	$1,093
Hyundai Kia-K	$518	$624	$840	$797
JLR	$128	$332	$1,283	$1,708
Mazda	$7	$207	$612	$1,411
Mitsubishi	$0	$0	$1,557	$1,482
Nissan	$360	$453	$1,143	$1,166
Subaru	$6	$26	$50	$101
Tesla	$0	$0	$0	$0
Toyota	$125	$597	$655	$978
Volvo	$714	$634	$603	$551
VWA	$0	$97	$318	$727
TOTAL	$330	$524	$759	$1,000

Overall, EPA estimates the costs of the final standards at $1,000 per vehicle relative to the no action scenario. The increase in costs between MYs 2024 and 2025 under the rule is a result of the elimination of advanced technology multiplier credits in combination with the increased stringency between MY 2024 and MY 2025.

Of note is the difference in costs per vehicle for the Framework manufacturers (BMW, Ford, Honda, Volvo and VWA) and the non-Framework manufacturers (with the exception of Subaru) with the Framework manufacturers showing several hundreds of dollars lower costs. Since the Framework manufacturers are incurring costs associated with the Framework, their incremental costs to meet the final standards, which are more stringent than the Framework, are lower than for those non-Framework manufacturers that have chosen to comply with the SAFE FRM.

The MY 2026 projected cost per vehicle is roughly the same as was previously estimated for the proposed standards in the NPRM despite the final standards being more stringent (RIA 4.1.3.2 presents the updated costs per vehicle for the proposed standards as an alternative). This is due primarily to two factors: lower battery costs resulting in more BEVs and, in turn, less technology applied to gasoline vehicles. The first factor is the updated battery costs, which are about 24 percent lower than those estimated in the NPRM. This reduces the per vehicle cost of electrified vehicles, which in turn increases the technology penetration of electrified technologies. The increased penetration of electrified vehicle technologies, and especially BEV technology (which with a 0 g/mile compliance value having such a large impact), results in less technology application on conventional, non-electrified gasoline and diesel vehicles. These two factors, lower battery costs resulting in more BEVs and less technology applied to gasoline vehicles explains how, on average, the final rule's per vehicle costs are so similar to the proposal's per vehicle costs. In Section 4.1.5 where we present our sensitivity results, we present more information surrounding this BEV penetration impact on ICE technology costs. We also present results with lower battery costs and higher battery costs than used in our primary analysis to present what costs could be if battery costs are lower or higher than we have projected. We also present costs that exclude hybridization to show what might happen if industry chooses to rely largely on ICE and plug-in vehicles rather than investing in hybridization too.

Costs per vehicle continue to rise through MY 2028 before starting to decrease as shown in Table 4-23. Importantly, the final rule results in higher BEV penetration estimates than those estimated in the NPRM. Also, we have chosen to stop the rate of learning after 2029, unlike in the NPRM, where we allowed battery costs to continue to decline. Applying the existing learning rates to the downward adjusted costs past the time frame of the rule would have produced costs gradually declining to levels that are difficult to empirically support at this time, due in part to uncertainties about the effect of increased demand for critical minerals and other factors, which we also received comment on. To account for this uncertainty in the context of the downward adjusted battery costs, we held the battery cost learning curve constant after 2029 to prevent projected future reductions in cost to exceed what we can currently technically demonstrate. This has the effect of reducing the rate of per-vehicle cost reductions year-over-year in the outer years out to 2050, compared to the NPRM. As previously explained in Section 2.3.4 and 4.1.1.2, we believe that holding learning constant after 2029 is likely a conservative assumption, as we would expect some level of continued learning beyond 2029 but there is uncertainty at this point on what the appropriate level of learning would be.

Table 4-23 Costs per Vehicle Projected through 2050 for the Final Standards (2018 dollars per vehicle)

Year	Car	Light Truck	Total
2023	$150	$485	$330
2024	$288	$732	$524
2025	$586	$909	$759
2026	$596	$1,356	$1,000
2027	$802	$1,469	$1,159
2028	$908	$1,462	$1,207
2029	$839	$1,381	$1,132
2030	$823	$1,377	$1,117
2031	$816	$1,374	$1,110
2032	$807	$1,366	$1,098
2033	$796	$1,353	$1,085
2034	$783	$1,341	$1,071
2035	$772	$1,324	$1,055
2036	$766	$1,307	$1,042
2037	$755	$1,286	$1,025
2038	$748	$1,279	$1,017
2039	$742	$1,273	$1,010
2040	$736	$1,269	$1,004
2041	$731	$1,266	$998
2042	$726	$1,261	$992
2043	$723	$1,260	$990
2044	$720	$1,247	$981
2045	$718	$1,246	$980
2046	$715	$1,244	$977
2047	$713	$1,243	$974
2048	$714	$1,242	$974
2049	$714	$1,237	$972
2050	$712	$1,233	$969

4.1.3.2 Alternatives

Car, truck, and fleet average vehicle costs for the Proposal and Alternative 2 minus 10 standards relative to the no action scenario (framework OEMs meeting the framework, non-framework OEMs meeting SAFE) are summarized in Table 4-24, Table 4-25 and Table 4-26.

Table 4-24: Car Average Cost per Vehicle for the Proposal and Alternative 2 minus 10 Standards Relative to the No Action Scenario (2018 dollars)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	-$9	$90	$460	$416	$138	$535	$634	$563
Daimler	$53	$343	$302	$319	$241	$272	$243	$219
FCA	$250	$202	$153	$328	$270	$239	$193	$349
Ford	$21	$22	$231	$208	$361	$338	$532	$494
General Motors	$941	$848	$923	$888	$2,217	$2,022	$1,968	$1,856
Honda	$24	$26	$112	$104	$48	$297	$339	$300
Hyundai Kia-H	$24	$61	$689	$665	$483	$498	$633	$606
Hyundai Kia-K	$126	$229	$635	$600	$204	$252	$328	$315
JLR	$25	$256	$251	$246	$47	$468	$452	$436
Mazda	$5	$394	$471	$427	$326	$769	$820	$745
Mitsubishi	$0	$0	$682	$676	$0	$0	$916	$899
Nissan	$251	$308	$939	$865	$398	$486	$1,430	$1,330
Subaru	$18	$18	$17	$14	$18	$18	$18	$251
Tesla	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$20	$374	$530	$503	$37	$323	$479	$497
Volvo	$0	$0	$120	$118	$0	-$1	-$2	-$7
VWA	-$175	-$111	-$86	$143	$327	$615	$591	$877
TOTAL	$171	$257	$506	$493	$465	$561	$741	$724

Table 4-25: Light Truck Average Cost per Vehicle for the Proposal and Alternative 2 minus 10 Standards Relative to the No Action Scenario (2018 dollars)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	-$154	-$152	-$131	-$130	$441	$410	$380	$351
Daimler	$6	$6	$697	$1,383	$2,514	$2,234	$2,069	$4,502
FCA	$1,490	$1,356	$1,266	$1,378	$1,714	$1,558	$1,409	$1,840
Ford	$38	$378	$361	$278	$224	$497	$460	$775
General Motors	$235	$338	$1,064	$1,188	$349	$656	$842	$1,322
Honda	-$11	$288	$370	$342	$128	$969	$985	$911
Hyundai Kia-H	$0	$0	$0	$1,999	$553	$542	$532	$5,400
Hyundai Kia-K	$851	$932	$860	$798	$2,096	$1,973	$1,808	$1,663
JLR	$26	$111	$821	$1,292	$429	$713	$1,565	$2,048
Mazda	$0	$0	$764	$1,315	$77	$76	$792	$2,089
Mitsubishi	$0	$0	$1,068	$1,031	$0	$0	$2,160	$2,028
Nissan	$475	$469	$451	$785	$699	$703	$677	$1,020
Subaru	$0	$9	$9	$8	$2	$85	$176	$175
Tesla	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$164	$661	$601	$628	$667	$1,127	$1,037	$1,692
Volvo	$472	$426	$392	$363	$871	$778	$704	$641
VWA	-$8	-$7	$121	$159	$986	$1,322	$1,566	$1,555
TOTAL	$364	$500	$679	$775	$689	$893	$938	$1,369

Table 4-26: Fleet Average Cost per Vehicle for the Proposal and Alternative 2 minus 10 Standards Relative to the No Action Scenario (2018 dollars)

	Proposal Standards				Alternative 2 minus 10 Standards			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026
BMW	-$62	$2	$247	$220	$252	$491	$543	$484
Daimler	$29	$180	$484	$813	$1,347	$1,210	$1,108	$2,240
FCA	$1,297	$1,170	$1,085	$1,205	$1,489	$1,345	$1,212	$1,597
Ford	$33	$282	$325	$259	$260	$453	$478	$698
General Motors	$481	$519	$1,016	$1,085	$996	$1,136	$1,241	$1,516
Honda	$9	$134	$218	$202	$82	$580	$611	$555
Hyundai Kia-H	$21	$55	$623	$788	$488	$500	$621	$1,055
Hyundai Kia-K	$373	$464	$712	$669	$856	$835	$826	$766
JLR	$26	$120	$793	$1,238	$411	$703	$1,509	$1,965
Mazda	$1	$202	$607	$844	$201	$427	$799	$1,382
Mitsubishi	$0	$0	$882	$859	$0	$0	$1,562	$1,484
Nissan	$314	$353	$808	$846	$484	$547	$1,225	$1,249
Subaru	$5	$12	$14	$13	$7	$71	$139	$199
Tesla	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$82	$494	$561	$559	$308	$664	$715	$997
Volvo	$351	$316	$321	$300	$650	$580	$525	$476
VWA	-$78	-$52	$31	$154	$707	$1,021	$1,152	$1,268
TOTAL	$275	$386	$598	$644	$586	$740	$850	$1,070

4.1.4 Technology Penetration Rates

4.1.4.1 Final Rule

Many manufacturers have projected aggressive moves toward electrification in the coming years, with several manufacturers projecting a complete transition to plug-in vehicles by 2030 or 2035, as previously described in section 0. Today's rule sets new standards through 2026, however it is intended to begin a future transition toward electrification. Table 4-27 shows the penetration rate of BEV+PHEV technology under the No Action scenario. Table 4-28, Table Table 4-29, and Table 4-30 show the penetration rate of BEV+PHEV technology with the remaining share being traditional ICE and/or advanced ICE technology under today's final standards. Values shown reflect fleet penetration and are not increments from the SAFE standards or other standards. The combined fleet technology penetrations for ICE vehicles are shown in Table 4-31.

Table 4-27 BEV+PHEV Penetration Rates under the No Action Scenario

	Car				Light Truck				Fleet			
Manufacturer	2023	2024	2025	2026	2023	2024	2025	2026	2023	2024	2025	2026
BMW	4%	8%	10%	17%	10%	10%	10%	10%	6%	9%	10%	14%
Daimler	12%	12%	13%	13%	8%	8%	8%	8%	10%	10%	10%	11%
FCA	17%	18%	19%	19%	1%	1%	1%	1%	3%	4%	4%	4%
Ford	13%	13%	14%	19%	1%	1%	3%	6%	5%	5%	6%	10%
General Motors	5%	5%	5%	6%	0%	1%	1%	1%	2%	2%	3%	3%
Honda	1%	1%	3%	7%	0%	6%	8%	8%	1%	3%	6%	8%
Hyundai Kia-H	8%	7%	7%	7%	0%	0%	0%	0%	7%	7%	7%	7%
Hyundai Kia-K	2%	1%	1%	2%	0%	0%	0%	0%	1%	1%	1%	1%
JLR	0%	0%	0%	0%	16%	16%	16%	16%	15%	15%	15%	15%
Mazda	7%	7%	7%	7%	0%	0%	0%	0%	3%	4%	4%	4%
Mitsubishi	3%	3%	3%	3%	0%	0%	0%	0%	2%	2%	2%	2%
Nissan	2%	2%	2%	2%	0%	0%	0%	0%	1%	1%	1%	1%
Subaru	0%	0%	0%	0%	1%	1%	1%	1%	0%	0%	0%	0%
Tesla	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Toyota	2%	2%	3%	3%	0%	0%	0%	0%	1%	1%	2%	2%
Volvo	3%	3%	4%	11%	13%	13%	14%	14%	10%	10%	12%	14%
VWA	16%	17%	17%	17%	11%	11%	11%	11%	13%	13%	13%	14%
TOTAL	9%	9%	9%	10%	2%	2%	3%	3%	5%	5%	6%	7%

Table 4-28: Car BEV+PHEV Penetration Rates under the Final Standards

Manufacturer	2023	2024	2025	2026
BMW	4%	9%	22%	29%
Daimler	15%	18%	18%	19%
FCA	20%	22%	22%	22%
Ford	13%	13%	16%	21%
General Motors	11%	11%	11%	13%
Honda	2%	5%	8%	12%
Hyundai Kia-H	10%	10%	18%	18%
Hyundai Kia-K	3%	3%	8%	8%
JLR	0%	3%	3%	3%
Mazda	7%	13%	13%	13%
Mitsubishi	3%	3%	3%	3%
Nissan	3%	3%	17%	17%
Subaru	0%	0%	0%	3%
Tesla	100%	100%	100%	100%
Toyota	2%	6%	9%	9%
Volvo	3%	3%	4%	11%
VWA	16%	17%	17%	25%
TOTAL	10%	12%	16%	17%

Table 4-29: Light Truck BEV+PHEV Penetration Rates under the Final Standards

Manufacturer	2023	2024	2025	2026
BMW	10%	10%	10%	10%
Daimler	8%	8%	21%	56%
FCA	13%	13%	13%	18%
Ford	1%	7%	8%	17%
General Motors	4%	8%	14%	18%
Honda	0%	13%	17%	17%
Hyundai Kia-H	0%	0%	0%	23%
Hyundai Kia-K	11%	11%	11%	11%
JLR	16%	16%	28%	35%
Mazda	0%	0%	0%	21%
Mitsubishi	0%	0%	16%	16%
Nissan	4%	5%	5%	9%
Subaru	1%	1%	1%	1%
Tesla	100%	100%	100%	100%
Toyota	1%	12%	12%	16%
Volvo	22%	22%	23%	23%
VWA	11%	12%	12%	18%
TOTAL	5%	9%	11%	17%

Table 4-30: Fleet BEV+PHEV Penetration Rates under the Final Standards

Manufacturer	2023	2024	2025	2026
BMW	6%	10%	18%	22%
Daimler	12%	14%	20%	36%
FCA	14%	15%	15%	18%
Ford	5%	9%	10%	18%
General Motors	6%	9%	13%	16%
Honda	1%	8%	12%	14%
Hyundai Kia-H	9%	9%	17%	19%
Hyundai Kia-K	6%	6%	9%	9%
JLR	15%	15%	26%	34%
Mazda	3%	7%	7%	17%
Mitsubishi	2%	2%	10%	10%
Nissan	3%	4%	14%	15%
Subaru	0%	0%	0%	1%
Tesla	100%	100%	100%	100%
Toyota	2%	9%	10%	12%
Volvo	17%	17%	18%	20%
VWA	13%	14%	14%	21%
TOTAL	7%	10%	14%	17%

Table 4-31: Fleet ICE Technology Penetration Rates under the Final Standards

Technology	2023		2024		2025		2026	
	No-action	Final	No-action	Final	No-action	Final	No-action	Final
Gasoline Direct Injection (without turbo, HCR, HEV, etc.)	21%	20%	15%	12%	13%	8%	9%	5%
Cylinder deactivation	9%	8%	8%	7%	6%	5%	6%	6%
Turbocharging level 1	25%	23%	23%	22%	22%	18%	20%	15%
Turbocharging level 2	0%	0%	0%	0%	0%	0%	0%	0%
Cooled EGR	0%	0%	0%	0%	0%	0%	0%	0%
High compression ratio level 0	4%	4%	2%	2%	2%	2%	3%	2%
High compression ratio level 1	18%	21%	26%	30%	28%	33%	32%	36%
High compression ratio level 2	0%	0%	0%	0%	0%	0%	0%	0%
Mild hybrid	3%	3%	3%	4%	3%	4%	5%	5%
Strong hybrid P2	2%	3%	2%	3%	2%	3%	2%	6%
Strong hybrid Powersplit	3%	3%	3%	2%	3%	1%	2%	1%
PHEV	1%	1%	1%	1%	1%	1%	0%	1%
BEV	4%	7%	5%	10%	5%	13%	6%	17%
Mass reduction 0	21%	19%	20%	13%	17%	9%	13%	4%
Mass reduction 1	18%	16%	19%	20%	21%	22%	25%	24%
Mass reduction 2	20%	18%	19%	10%	19%	9%	18%	8%
Mass reduction 3	31%	37%	32%	45%	32%	47%	33%	49%
Mass reduction 4	10%	10%	11%	11%	11%	12%	11%	14%
Mass reduction 5	0%	0%	0%	0%	0%	0%	0%	0%
Mass reduction 6	0%	0%	0%	0%	0%	0%	0%	0%
Curb Weight reduction (relative to MR0)	5.0%	5.2%	5.1%	5.7%	5.3%	5.9%	5.4%	6.3%

This final rule includes advanced technology multipliers. A recent working paper by Gillingham (2021) uses a stylized model to examine the effects of EV multipliers on EV adoption and conventional vehicle emission reductions.[22] He finds that, under some conditions, multipliers may reduce EV adoption and increase vehicle emissions; under other conditions, they may increase EV adoption and decrease vehicle emissions. In particular, under the conditions of low levels of EV market share and EV costs higher than those of conventional vehicles, EV multiplier incentives are expected to increase EV penetration. Gillingham (2021) states that tightening the standards in addition to allowing multipliers will "offset the standard-weakening effect of the generous crediting." Gillingham acknowledges the stylized nature of his model and suggests examining the effectiveness of advanced technology multipliers with more detailed models in regulatory analyses, citing as an example the NHTSA CAFE model. As part of the analysis for this proposed rule, EPA has estimated the benefits and costs of this rule with and without the advanced technology multipliers in a memo to the docket. For reasons discussed in Preamble Section II.B.1, we are finalizing the limited use of multipliers to promote commercialization of advanced technologies and to provide compliance flexibility.

To help shed light on the impact of advanced technology multipliers on the penetration rates of BEVs and PHEVs, we conducted model runs without the multipliers. Those results along with the results of the runs with multipliers are shown in Table 4-32. The results presented in this table suggest that the advanced technology multipliers are not expected to have a large impact on BEV and PHEV technology penetration.

Table 4-32: Impact of Advanced Technology Multipliers on the Penetration of BEV and PHEV Technology

	2023	2024	2025	2026
Final standards, with multipliers	7%	10%	14%	17%
Final standards, without multipliers	8%	11%	13%	17%

4.1.4.2 Alternatives

Table 4-33, Table 4-34, and Table 4-35 show the penetration rate of BEV+PHEV technology with the remaining share being traditional ICE and/or advanced ICE technology for the Proposal standards and the Alternative 2 minus 10 standards. Values shown reflect fleet penetration and are not increments from the SAFE standards or other standards.

Table 4-33: Car BEV+PHEV Penetration Rates under the Proposal and Alternative 2 minus 10 Standards

Manufacturer	**Proposal Standards**				**Alternative 2 minus 10 Standards**			
	2023	2024	2025	2026	2023	2024	2025	2026
BMW	4%	9%	17%	23%	4%	13%	17%	24%
Daimler	13%	16%	16%	17%	15%	15%	15%	15%
FCA	20%	22%	22%	22%	20%	21%	22%	22%
Ford	13%	13%	16%	21%	13%	13%	16%	21%
General Motors	16%	16%	16%	17%	29%	30%	30%	32%
Honda	1%	1%	4%	8%	2%	5%	7%	11%
Hyundai Kia-H	8%	8%	16%	16%	14%	14%	16%	16%
Hyundai Kia-K	3%	3%	8%	8%	3%	3%	4%	4%
JLR	0%	0%	0%	0%	0%	0%	0%	0%
Mazda	7%	13%	13%	13%	11%	17%	17%	17%
Mitsubishi	3%	3%	3%	3%	4%	3%	3%	3%
Nissan	4%	5%	14%	14%	4%	4%	18%	18%
Subaru	0%	0%	0%	0%	0%	0%	0%	3%
Tesla	100%	100%	100%	100%	100%	100%	100%	100%
Toyota	2%	4%	7%	7%	3%	3%	5%	6%
Volvo	3%	3%	4%	11%	3%	3%	4%	11%
VWA	14%	15%	15%	19%	20%	23%	23%	28%
TOTAL	10%	11%	15%	16%	13%	14%	17%	19%

Table 4-34: Light Truck BEV+PHEV Penetration Rates under the Proposal and Alternative 2 minus 10 Standards

Manufacturer	**Proposal Standards**				**Alternative 2 minus 10 Standards**			
	2023	2024	2025	2026	2023	2024	2025	2026
BMW	10%	10%	10%	10%	14%	14%	14%	14%
Daimler	8%	8%	21%	27%	33%	33%	33%	68%
FCA	11%	11%	11%	12%	13%	13%	13%	17%
Ford	1%	6%	7%	9%	1%	5%	6%	15%
General Motors	3%	7%	13%	13%	3%	5%	6%	11%
Honda	0%	8%	12%	12%	0%	13%	17%	17%
Hyundai Kia-H	0%	0%	0%	0%	0%	0%	0%	46%
Hyundai Kia-K	8%	8%	8%	8%	20%	20%	20%	20%
JLR	16%	16%	24%	31%	18%	19%	30%	38%
Mazda	0%	0%	0%	0%	0%	0%	0%	14%
Mitsubishi	0%	0%	4%	4%	0%	0%	16%	16%
Nissan	4%	4%	4%	7%	4%	4%	4%	7%
Subaru	1%	1%	1%	1%	1%	1%	1%	1%
Tesla	100%	100%	100%	100%	100%	100%	100%	100%
Toyota	1%	11%	11%	12%	4%	14%	14%	21%
Volvo	16%	16%	18%	18%	21%	21%	22%	22%
VWA	11%	11%	11%	11%	11%	15%	15%	15%
TOTAL	4%	8%	10%	11%	6%	9%	10%	16%

Table 4-35: Fleet BEV+PHEV Penetration Rates under the Proposal and Alternative 2 minus 10 Standards

Manufacturer	Proposal Standards				Alternative 2 minus 10 Standards			
	2023	2024	2025	2026	2023	2024	2025	2026
BMW	6%	10%	14%	19%	8%	13%	16%	20%
Daimler	10%	12%	19%	22%	24%	24%	24%	40%
FCA	12%	12%	13%	14%	14%	14%	14%	18%
Ford	5%	8%	10%	12%	4%	7%	9%	16%
General Motors	8%	10%	14%	15%	12%	14%	14%	18%
Honda	1%	4%	7%	10%	1%	8%	11%	14%
Hyundai Kia-H	7%	7%	15%	15%	13%	13%	15%	19%
Hyundai Kia-K	5%	5%	8%	8%	9%	9%	9%	9%
JLR	15%	15%	22%	30%	17%	18%	29%	36%
Mazda	3%	7%	7%	7%	5%	9%	9%	16%
Mitsubishi	2%	2%	4%	4%	2%	2%	10%	10%
Nissan	4%	4%	11%	12%	4%	4%	14%	15%
Subaru	0%	0%	0%	0%	0%	0%	0%	1%
Tesla	100%	100%	100%	100%	100%	100%	100%	100%
Toyota	2%	7%	9%	9%	3%	8%	9%	12%
Volvo	13%	13%	14%	16%	16%	16%	18%	19%
VWA	12%	13%	13%	14%	15%	18%	18%	21%
TOTAL	7%	9%	12%	13%	9%	12%	14%	17%

Note that Alternative 2 minus 10 has slightly higher BEV+PHEV penetration in the early years but then lower BEV+PHEV penetration in the later years, although these differences are very small and likely within the model's variability. This can be explained by, at least, three important considerations. The first of these being the advanced technology multipliers in the final standards in both MYs 2023 and 2024 which Alternative 2 minus 10 does not have. Those multipliers serve to hinder slightly the BEV+PHEV penetration due to their multiplicative effect. The reverse is then true in the later years. Having introduced more BEVs and PHEVs in the early years under Alternative 2 minus 10, slightly fewer are needed in later years to "make up" for the slower pace of technology introduction in those earlier years where multipliers are provided. This characterization of technology penetration, of course, ignores the impacts of multipliers on costs where multipliers provide manufacturers with more flexibility in achieving compliance which serves to reduce costs in the early years.

4.1.4.3 Fleet Mix

The version of CCEMS used by EPA makes use of a dynamic fleet share model that estimates, separately, the shares of passenger cars and light trucks based on vehicle characteristics, and then adjusts them so that the market shares sum to one. As such, fleet mix can change depending on the standards within a given modeled scenario. Table 4-36 shows the fleet mix projections for the final standards and each of the alternatives.

Table 4-36 Fleet Mix Projections for the Final Standards, Proposal and Alternative 2 minus 10

Model Year	Final Standards		Proposal		Alternative 2 minus 10	
	Car	Light Truck	Car	Light Truck	Car	Light Truck
2020	44%	56%	44%	56%	44%	56%
2021	44%	56%	44%	56%	44%	56%
2022	46%	54%	46%	54%	46%	54%
2023	46%	54%	46%	54%	46%	54%
2024	47%	53%	47%	53%	47%	53%
2025	47%	53%	47%	53%	47%	53%
2026	47%	53%	48%	52%	47%	53%

The net benefits for a given set of standards depend in large part on how those standards affect the fleet mix. In this rule, as discussed in Chapter 8.1.2 and Preamble Section VII.B, CCEMS uses the dynamic fleet share modeling from DOE’s National Energy Modeling System (NEMS). EPA will continue to assess fleet mix questions in subsequent rulemakings, including consumer and producer decisions between cars and light trucks, any possible “upsizing” effect of the standards, and questions about how modeled fleet share results compare with observed trends (e.g., current and future AEO estimates).

4.1.5 <u>Sensitivities</u>

We have conducted the following sensitivities:

- AEO high oil price (AEO high)
- AEO low oil price (AEO low)
- Allow HCR2 in MY 2025 and later (Allow HCR2)
- Battery costs higher
- Battery costs lower (battery costs roughly 24 percent lower than the updated FRM costs)
- Sales demand elasticity of -0.15
- Sales demand elasticity of -1.0

- Mass safety coefficients at the 5th percentile (Mass safety 5th pctile)
- Mass safety coefficients at the 95th percentile (Mass safety 95th pctile)
- No further application of mild or strong hybrid technology (no hybrids)
- Perfect trading, which allows perfect trading of CO_2 credits between manufacturers[c]
- Rebound rate of -5 percent
- Rebound rate of -15 percent

Each sensitivity is compared to its own no action scenario. In other words, the no action standards were used but the no action scenario was run using the same set of sensitivity parameters as used for the action scenario.

The high and low battery cost sensitivity cases were selected to evaluate the effect of variations in battery cost. Figure 4-3 illustrates the range of costs using an example of a 60 kWh battery and its direct manufacturing cost (DMC) under each sensitivity case. The solid line depicts the costs applicable to the primary case, which as described in Sections 2.3.4 and 4.1.1.2, reduced costs during the time frame of the rule by about 24 percent from the proposal, and flattened learning beginning in MY 2029. For the high cost case, we used the battery costs from the proposal, until MY 2035 when we merged them with the primary case. For the low cost case, we reduced costs during the time frame of the rule by about 33 percent from the proposal, and allowed learning to proceed at the rates defined by the battery learning curve that was used in the proposal.

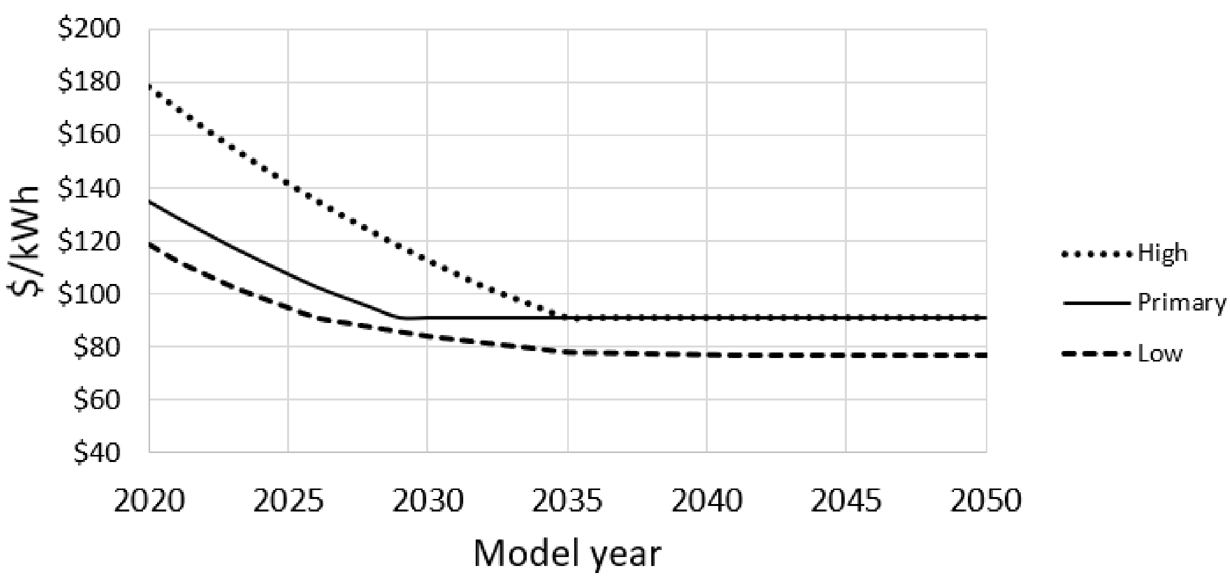

Figure 4-3. Battery cost sensitivity cases in terms of $/kWh DMC for a representative 60 kWh battery

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[c] To simulate perfect trading, the entire fleet is attributed to a single manufacturer, dubbed "Industry," in the market input file.

The high oil price and low oil price sensitivities use the fuel prices shown in Figure 4-4.

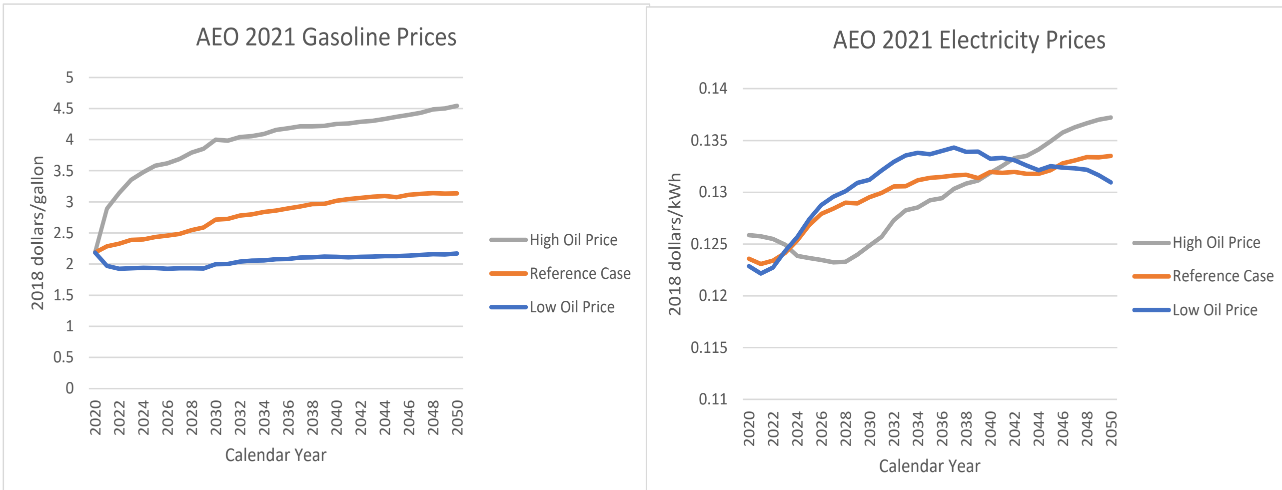

Figure 4-4 Gasoline and Electricity Prices used in the Primary and Sensitivity Analyses

4.1.5.1 Compliance Costs per Vehicle and Technology Penetration

The per-vehicle compliance costs for the final rule and for each of the analyzed sensitivities are shown in Table 4-37. The technology penetration rates for the final rule and for each of the analyzed sensitivities are shown in Table 4-38 and Table 4-39. Note that the costs per vehicle and the technology penetration rates for the mass safety and rebound sensitivities are identical to those for the final standards since those sensitivities have no impact on compliance; therefore, those results are not shown in the tables that follow.

Table 4-37: Costs per Vehicle for the Final Standards and Sensitivities relative to their No Action Scenarios (2018 dollars)*

Model Year	Final	AEO high	AEO low	Allow HCR2	Battery costs higher	Battery costs lower	Demand elasticity -0.15	Demand elasticity -1.0	No hybrids	Perfect trading
2021	$72	$65	$76	$72	$101	$40	$72	$72	$78	$6
2022	$185	$156	$211	$185	$223	$151	$185	$185	$185	$21
2023	$330	$297	$380	$331	$445	$288	$329	$328	$315	$147
2024	$524	$480	$563	$524	$760	$454	$522	$521	$510	$360
2025	$759	$753	$805	$760	$1,092	$708	$759	$758	$826	$772
2026	$1,000	$951	$1,040	$986	$1,398	$909	$1,000	$999	$1,023	$1,061

Table 4-38: MY 2026 Technology Penetration Rates for the No-Action and Final Standards in the AEO High, AEO Low, Allow HCR2 and No Hybrids Sensitivities

	Final		AEO high		AEO low		Allow HCR2		No hybrids	
Technology	No-Action	Final	No-Action	Final	No-Action	Final	No-Action	Final	No-Action	Final
DEAC	6%	6%	7%	5%	6%	6%	6%	6%	8%	6%
TURBO1	20%	15%	18%	15%	20%	14%	20%	15%	19%	16%
HCR1	32%	36%	37%	37%	30%	35%	31%	32%	32%	35%
HCR2	0%	0%	0%	0%	0%	0%	1%	4%	0%	0%
AT8	26%	21%	25%	21%	27%	22%	26%	22%	26%	23%
AT8L2	7%	3%	4%	2%	7%	3%	7%	3%	8%	4%
AT8L3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AT9L2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AT10L2	22%	17%	22%	15%	23%	18%	22%	18%	24%	22%
AT10L3	2%	3%	2%	3%	2%	3%	2%	3%	2%	3%
SS12V	40%	31%	36%	28%	42%	32%	40%	32%	46%	42%
BISG	5%	5%	5%	5%	5%	5%	5%	5%	2%	1%
SHEVP2	2%	6%	2%	5%	2%	5%	2%	4%	0%	0%
SHEVPS	2%	1%	2%	1%	2%	1%	2%	1%	2%	1%
P2HCR1	2%	4%	2%	3%	2%	4%	2%	4%	0%	0%
PHEV	0%	1%	1%	1%	0%	1%	0%	1%	0%	1%
BEV	6%	17%	7%	17%	6%	17%	6%	17%	8%	19%
MR0	13%	4%	5%	4%	15%	5%	13%	4%	13%	4%
MR1	25%	24%	31%	24%	23%	22%	25%	25%	23%	22%
MR2	18%	8%	18%	7%	18%	8%	18%	8%	18%	8%
MR3	33%	49%	35%	51%	33%	52%	33%	50%	32%	50%
MR4	11%	14%	11%	12%	12%	14%	11%	12%	14%	16%
MR5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
MR6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 4-39 MY 2026 Technology Penetration Rates for the No-Action and Final Standards in the Battery Costs Higher and Lower, Demand Elasticity of -0.15 and -1.0 and the Perfect Trading Sensitivities

	Battery costs higher		Battery costs lower		Demand elasticity -0.15		Demand elasticity -1.0		Perfect trading	
Technology	No-Action	Final	No-Action	Final	No-Action	Final	No-Action	Final	No-Action	Final
DEAC	6%	5%	8%	6%	6%	6%	6%	6%	10%	10%
TURBO1	18%	13%	21%	16%	20%	15%	20%	15%	30%	23%
HCR1	31%	36%	32%	34%	32%	36%	32%	36%	25%	26%
HCR2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AT8	25%	12%	26%	23%	26%	21%	26%	21%	36%	29%
AT8L2	5%	3%	7%	4%	7%	3%	7%	3%	2%	1%
AT8L3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AT9L2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AT10L2	25%	17%	22%	17%	22%	17%	21%	17%	22%	18%
AT10L3	3%	7%	2%	3%	2%	3%	2%	3%	0%	1%
SS12V	41%	27%	40%	32%	40%	31%	40%	31%	46%	37%
BISG	4%	5%	6%	6%	5%	5%	5%	5%	5%	5%
SHEVP2	2%	10%	1%	3%	2%	6%	2%	6%	0%	3%
SHEVPS	3%	2%	2%	1%	2%	1%	2%	1%	2%	1%
P2HCR1	2%	6%	2%	3%	2%	4%	2%	4%	2%	3%
PHEV	2%	5%	0%	0%	0%	1%	0%	1%	0%	1%
BEV	5%	11%	7%	20%	6%	17%	6%	17%	7%	16%
MR0	13%	4%	13%	4%	13%	4%	13%	4%	12%	5%
MR1	20%	15%	26%	33%	25%	24%	25%	24%	27%	27%
MR2	16%	9%	18%	11%	18%	8%	18%	8%	17%	11%
MR3	33%	36%	33%	41%	33%	49%	33%	49%	32%	45%
MR4	18%	36%	10%	11%	11%	14%	11%	14%	12%	12%
MR5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
MR6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

4.1.5.2 How Battery Costs Impact Non-BEV Vehicle Costs in our Modeling

In Chapter 4.1.3, we noted that the reduced battery costs had the effect of not only reducing average per vehicle costs, but that their lower costs combined with the higher BEV penetration has the effect of lowering the technology needed on other vehicles. Likewise, higher battery costs have the effect of reducing BEV penetration and increasing the technology (and costs) of other vehicles. This is illustrated in Table 4-40 which compares the contribution to the average cost per vehicle by vehicles having the various powertrains in MY 2026 for our Final standards to the costs of those same standards using our higher battery cost estimates.

Table 4-40 Cost Contributions Comparing our Primary Battery Costs to the Higher Battery Costs (2018 dollars per Vehicle)

Powertrain	Final		Final with Higher Battery Costs	
	Share of Vehicles in Powertrain Category	Contribution to $/vehicle	Share of Vehicles in Powertrain Category	Contribution to $/vehicle
Conventional	36%	$296	34%	$334
12V Start-Stop	31%	$188	27%	$202
Mild HEV	5%	$47	5%	$49
Strong HEV	10%	$280	18%	$573
PHEV	1%	$11	5%	$259
BEV	17%	$1,052	11%	$1,033
Fuel Cell	0%	$0	0%	$0
Sum *	100%	$1,873	100%	$2,450
* Note that costs presented here are not marginal costs relative to a "no action" scenario so will not be reflected elsewhere in this RIA.				

Two things stand out in this table:

- The lower BEV penetration when battery costs are higher (11 percent vs. 17 percent) results in stronger HEV penetration (18 percent vs. 10 percent) and, due to the higher battery costs, $293 greater contribution to the $/vehicle ($573 minus $280) in the higher battery cost case. The same is true of PHEVs, with the results being $248 greater contribution to the $/vehicle in the higher battery cost case.
- Non-electrified vehicle share actually decreases in the higher battery cost case, but their contribution to $/vehicle increases. With fewer BEVs, Conventional (or ICE) and start-stop vehicles must add more (and/or more costly) technology than they do in the primary case ($334 plus $202 giving $536 in the higher battery cost case, vs. $484 in the primary case).

Table 4-41 compares the contributions by vehicles having the various powertrains in MY 2026 for our Final standards to the costs of those same standards using our lower battery cost estimates.

Table 4-41 Cost Contributions Comparing our Primary Battery Costs to the Lower Battery Costs (2018 dollars per Vehicle)

Powertrain	Final		Final with Lower Battery Costs	
	Share of Vehicles in Powertrain Category	Contribution to $/vehicle	Share of Vehicles in Powertrain Category	Contribution to $/vehicle
Conventional	36%	$296	36%	$281
12V Start-Stop	31%	$188	32%	$168
Mild HEV	5%	$47	6%	$44
Strong HEV	10%	$280	6%	$156
PHEV	1%	$11	0%	$2
BEV	17%	$1,052	20%	$1,002
Fuel Cell	0%	$0	0%	$0
Sum *	100%	$1,873	100%	$1,653
* Note that costs presented here are not marginal costs relative to a "no action" scenario so will not be reflected elsewhere in this RIA.				

As with Table 4-40, the scenario with lower battery costs results, as expected, in more BEVs and even lower contributions from strong HEV and PHEV technologies to the average per vehicle cost driven in part by their lower battery costs but also their lower shares. The same Conventional and start-stop trend is shown here too with slightly less (and/or less costly) technology being added in the lower battery cost case.

These results support our statement that our primary battery costs, when compared to our higher battery costs, which are more similar to those used in our proposal, have a dual impact on the average per vehicle costs in that they result in higher BEV penetrations which then lowers the additional technology costs of other vehicles. Similarly, with lower battery costs than in our primary case, this impact becomes more pronounced.

4.2 Estimates of Fuel Economy Impacts

4.2.1 Final Rule

The estimated impacts on fuel economy associated with our No Action scenario and the final standards are shown in Table 4-42. Importantly, these fuel economy values are based on the standards and the model's estimated achieved levels, or rating, and therefore do not consider use of AC leakage credits. The fuel economy values are estimated using the average CO_2 content of the gasoline used for compliance testing (8887 grams CO_2 per gallon of certification gasoline). Table 4-43 presents the fuel economy values assuming full use of AC leakage credits where we have calculated the fuel economy again using the CO_2 content of certification gasoline and adding to the values shown in Table 4-42 the AC leakage credit. Because we expect full use of the AC leakage credit, the values shown in Table 4-43 are considered to be more indicative of the actual fuel economy values in compliance testing.

Perhaps of most interest are the estimated fuel economy impacts on-the-road, or the expected "EPA label values." Those fuel economy values are shown in Table 4-44 where we have multiplied the values shown in Table 4-43 by the anticipated "gap" of 0.8 to reflect the estimated real-world values relative to the test cycle values.

Table 4-42: Fuel Economy (MPG) Estimates based on the GHG Standards*

Regulatory Class	MY	No Action Scenario		Final Rule	
		Standard	Rating	Standard	Rating
Car	2023	51	53	54	56
	2024	52	55	56	60
	2025	53	56	60	63
	2026	54	57	67	66
Truck	2023	36	36	38	39
	2024	36	37	40	42
	2025	37	38	43	44
	2026	38	39	48	50
Combined	2023	41	43	44	45
	2024	42	44	46	49
	2025	43	45	50	51
	2026	45	46	55	57

* Calculated as 8887 divided by CO_2e. Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

Table 4-43: Fuel Economy (MPG) Estimates assuming full use of AC Leakage Credits*

Regulatory Class	MY	No Action Scenario		Final Rule	
		Standard	Rating	Standard	Rating
Car	2023	47	49	50	51
	2024	48	51	52	55
	2025	49	52	55	58
	2026	50	53	61	60
Truck	2023	33	34	35	36
	2024	34	35	37	39
	2025	35	36	40	40
	2026	36	37	44	46
Combined	2023	39	40	41	42
	2024	39	41	43	45
	2025	40	42	46	47
	2026	41	43	50	52

* Calculated as 8887 divided by (CO_2e + AC Leakage Credit). Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

Table 4-44: Fuel Economy (MPG) Estimated "Label Value"*

Regulatory Class	MY	No Action Scenario		Final Rule	
		Standard	Rating	Standard	Rating
Car	2023	38	39	40	41
	2024	38	41	42	44
	2025	39	41	44	46
	2026	40	42	49	48
Truck	2023	27	27	28	29
	2024	27	28	30	31
	2025	28	29	32	32
	2026	28	29	35	36
Combined	2023	31	32	33	33
	2024	32	33	34	36
	2025	32	34	37	38
	2026	33	34	40	41

* Calculated as 8887 divided by (CO_{2e} + AC Leakage Credit) then multiplied by 0.8. Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

4.2.2 Alternatives

Here we present the analogous series of tables presented in Chapter 4.2.1 but for each of the alternatives (i.e., the Proposal and Alternative).

Table 4-45: Fuel Economy (MPG) Estimates based on the GHG Standards for the Proposal Standards*

Regulatory Class	MY	No Action Scenario		Proposal	
		Standard	Rating	Standard	Rating
Car	2023	51	53	54	57
	2024	52	55	56	61
	2025	53	56	59	62
	2026	54	57	62	64
Truck	2023	36	36	38	38
	2024	36	37	40	41
	2025	37	38	42	42
	2026	38	39	44	45
Combined	2023	41	43	44	45
	2024	42	44	46	49
	2025	43	45	49	50
	2026	45	46	51	52

* Calculated as 8887 divided by CO_{2e}. Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

Table 4-46: Fuel Economy (MPG) Estimates Assuming Full Use of AC Leakage Credits for the Proposal Standards*

Regulatory Class	MY	No Action Scenario		Proposal	
		Standard	Rating	Standard	Rating
Car	2023	47	49	50	52
	2024	48	51	52	56
	2025	49	52	54	57
	2026	50	53	57	59
Truck	2023	33	34	35	36
	2024	34	35	37	38
	2025	35	36	39	39
	2026	36	37	41	41
Combined	2023	39	40	41	42
	2024	39	41	43	45
	2025	40	42	45	46
	2026	41	43	47	48
* Calculated as 8887 divided by (CO_{2e} + AC Leakage Credit). Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.					

Table 4-47: Fuel Economy (MPG) Estimated "Label Value" Under the Proposal Standards*

Regulatory Class	MY	No Action Scenario		Proposal	
		Standard	Rating	Standard	Rating
Car	2023	38	39	40	42
	2024	38	41	42	44
	2025	39	41	43	46
	2026	40	42	45	47
Truck	2023	27	27	28	29
	2024	27	28	30	31
	2025	28	29	31	31
	2026	28	29	33	33
Combined	2023	31	32	33	33
	2024	32	33	34	36
	2025	32	34	36	37
	2026	33	34	38	39
* Calculated as 8887 divided by (CO_{2e} + AC Leakage Credit) then multiplied by 0.8. Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.					

Table 4-48: Fuel Economy (MPG) Estimates Based on the GHG Standards of the Alternative 2 minus 10 Standards*

Regulatory Class	MY	No Action Scenario		Alternative 2 minus 10	
		Standard	Rating	Standard	Rating
Car	2023	51	53	54	57
	2024	52	55	57	61
	2025	53	56	60	65
	2026	54	57	67	68
Truck	2023	36	36	39	39
	2024	36	37	41	42
	2025	37	38	43	44
	2026	38	39	48	50
Combined	2023	41	43	45	45
	2024	42	44	47	49
	2025	43	45	50	52
	2026	45	46	55	57

* Calculated as 8887 divided by CO_{2e}. Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

Table 4-49: Fuel Economy (MPG) Estimates Assuming Full Use of AC Leakage Credits in the Alternative 2 minus 10 Standards*

Regulatory Class	MY	No Action Scenario		Alternative 2 minus 10	
		Standard	Rating	Standard	Rating
Car	2023	47	49	50	52
	2024	48	51	52	56
	2025	49	52	55	59
	2026	50	53	61	62
Truck	2023	33	34	36	36
	2024	34	35	38	39
	2025	35	36	40	40
	2026	36	37	44	45
Combined	2023	39	40	42	42
	2024	39	41	44	45
	2025	40	42	46	47
	2026	41	43	50	52

* Calculated as 8887 divided by (CO_{2e} + AC Leakage Credit). Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

Table 4-50: Fuel Economy (MPG) Estimated "Label Value" Under the Alternative 2 minus 10 Standards*

Regulatory Class	MY	No Action Scenario		Alternative 2 minus 10	
		Standard	Rating	Standard	Rating
Car	2023	38	39	40	42
	2024	38	41	42	45
	2025	39	41	44	47
	2026	40	42	49	49
Truck	2023	27	27	29	29
	2024	27	28	30	31
	2025	28	29	32	32
	2026	28	29	35	36
Combined	2023	31	32	33	34
	2024	32	33	35	36
	2025	32	34	36	38
	2026	33	34	40	41

* Calculated as 8887 divided by (CO_{2e} + AC Leakage Credit) then multiplied by 0.8. Note that the "rating" is the estimated compliance value and, as such, includes possible under compliance due to use of banked credits and/or over compliance for earning credits for future use.

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[1] 75 FR 25324.

[2] 77 FR 62624.

[3] EPA-420-D-16-900, July 2016.

[4] EPA-420-R-16-020, November 2016.

[5] EPA-420-R-17-001, January 2017.

[6] 85 FR 24218.

[7] See 86 FR 49602 and CAFE Model Documentation, August 2021.

[8] California Air Resources Board. Framework Agreements on Clean Cars. August 17, 2020. Last accessed on the Internet on 5/25/2021 at the following URL: https://ww2.arb.ca.gov/sites/default/files/2020-08/clean-car-framework-documents-all-bmw-ford-honda-volvo-vw.pdf

[9] 85 FR 24647.

[10] Science Advisory Board (SAB) Consideration of the Scientific and Technical Basis of the EPA's Proposed Rule titled The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, February 27, 2020.

[11] EPA CCEMS Post-Processing Tool, available in the docket and at https://github.com/USEPA/EPA_CCEMS_PostProcessingTool

[12] 85 FR 24174.

[13] EPA CCEMS Post-Processing Tool, available in the docket and at https://github.com/USEPA/EPA_CCEMS_PostProcessingTool.

[14] National Academies of Sciences, Engineering, and Medicine 2021. "Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy 2025-2035". Washington, DC: The National Academies Press. https://doi.org/10.17226/26092

[15] Bloomberg New Energy Finance, "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh," accessed on October 30, 2021 at https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

[16] National Academies of Sciences, Engineering, and Medicine 2021. "Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy 2025-2035". Washington, DC: The National Academies Press. https://doi.org/10.17226/26092, at p. 5-139.

[17] Massachusetts Institute of Technology, "Insights into Future Mobility," MIT Energy Initiative (2019).

[18] Hsieh, I-Yun Lisa et al., "Learning only buys you so much: Practical limits on battery price reduction." Applied Energy, 239 (April 2019): 218-224.

[19] 86 FR 49602.

[20] 86 FR 49602.

[21] EPA CCEMS Post-Processing Tool, available in the docket and at https://github.com/USEPA/EPA_CCEMS_PostProcessingTool.

[22] Gillingham, K. (2021). "Designing Fuel-Economy Standards in Light of Electric Vehicles." NBER working paper #29067.

Chapter 5: Projected Impacts on Emissions, Fuel Consumption, and Safety

This chapter documents EPA's analysis of the emission, fuel consumption and safety impacts of the emission standards for light-duty vehicles. Light-duty vehicles include passenger vehicles such as cars, sport utility vehicles, vans, and pickup trucks. Such vehicles are used for both commercial and personal uses and are significant contributors to the total United States (U.S.) GHG emission inventory.

5.1 Projected Emissions Impacts

5.1.1 Greenhouse Gas Emissions

5.1.1.1 Final Rule

EPA estimated the GHG emissions impacts associated with the Final standards, including impacts on tailpipe emissions from light-duty cars and trucks and the upstream emissions associated with the fuels used to power those vehicles (both at the refinery and the electricity generating unit). The tailpipe emissions of CO_2 are estimated internal to the model based on the policy scenario(s) being run (as controlled via the scenarios input file) and the projected compliance pathway which impacts the projected technology mix. The tailpipe emissions of CH_4 and N_2O make use of vehicle emission factors estimated by EPA's MOVES model.[a,1,2] The upstream emissions are then calculated using emission factors applied to the gallons of liquid fuels projected to be consumed and the kilowatt hours of electricity projected to be consumed. The upstream emission factors used in this final rule the modeling have been updated since EPA's proposed rule. The updated upstream emission factors are consistent with those used in the recent NHTSA CAFE proposal and were generated using the DOE/Argonne GREET model.[3] In this final rule we have not attempted to change past practices by projecting the final destinations of BEV's and PHEV's to estimate regional emission inventory impacts, however, we are performing additional research to potentially add that capability in future rulemakings. See Figure 5-1 through Figure 5-3 for a comparison of how our upstream emission factors have changed since the NPRM.

[a] EPA used identical CH4 and N2O vehicle tailpipe emission factors to those used by NHTSA in their August CAFE NPRM. See 86 FR 49602.

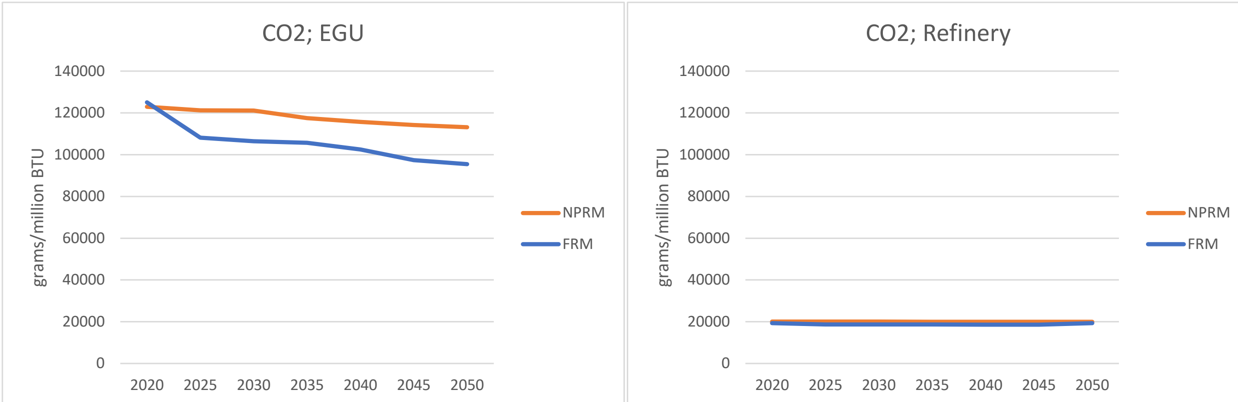

Figure 5-1 Electricity Generating Unit (EGU) and Refinery Emission Factors for CO_2

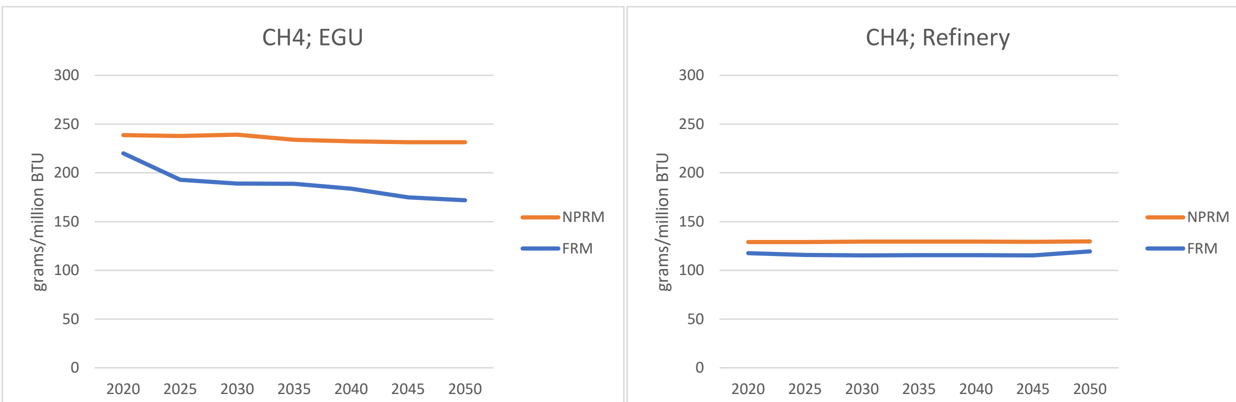

Figure 5-2 Electricity Generating Unit (EGU) and Refinery Emission Factors for CH_4

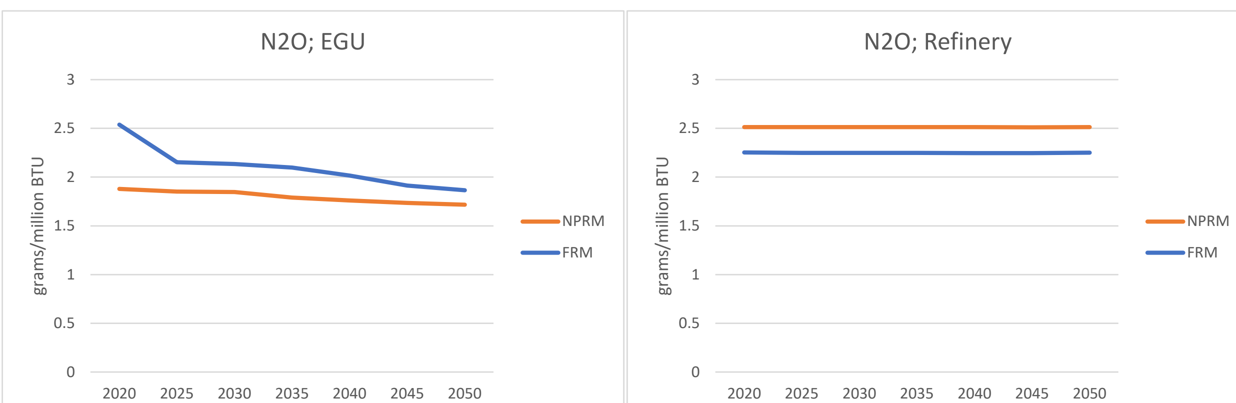

Figure 5-3 Electricity Generating Unit (EGU) and Refinery Emission Factors for N_2O

Table 5-1: Impacts on GHG Emissions under the Final Standards Relative to the No Action Scenario

Year	CO_2 Upstream (MMT)	CH_4 Upstream (metric tons)	N_2O Upstream (metric tons)	CO_2 Tailpipe (MMT)	CH_4 Tailpipe (metric tons)	N_2O Tailpipe (metric tons)
2023	0	-5,149	-120	-5	-11	-26
2024	1	-10,097	-233	-11	-23	-60
2025	1	-17,342	-402	-18	-43	-112
2026	2	-27,311	-636	-29	-71	-182
2027	2	-39,613	-919	-41	-103	-256
2028	2	-52,768	-1,221	-54	-145	-337
2029	3	-64,891	-1,499	-66	-192	-416
2030	3	-76,665	-1,769	-77	-244	-494
2031	3	-87,836	-2,024	-88	-292	-568
2032	4	-98,675	-2,271	-99	-342	-641
2033	4	-108,880	-2,504	-109	-392	-710
2034	4	-118,279	-2,722	-118	-440	-775
2035	4	-126,826	-2,921	-127	-571	-835
2036	5	-134,419	-3,099	-134	-619	-890
2037	5	-140,938	-3,253	-141	-662	-941
2038	5	-146,592	-3,387	-146	-701	-984
2039	5	-151,747	-3,506	-151	-735	-1,023
2040	5	-156,120	-3,607	-155	-764	-1,055
2041	5	-159,800	-3,691	-159	-787	-1,082
2042	5	-162,773	-3,759	-161	-807	-1,104
2043	4	-165,254	-3,815	-163	-823	-1,122
2044	4	-167,458	-3,863	-165	-836	-1,136
2045	4	-169,301	-3,902	-166	-846	-1,147
2046	3	-170,811	-3,933	-167	-854	-1,157
2047	3	-172,003	-3,957	-167	-861	-1,165
2048	3	-173,079	-3,978	-167	-866	-1,172
2049	2	-175,319	-3,992	-168	-869	-1,177
2050	2	-177,519	-4,005	-168	-872	-1,181
Sum	93	-3,257,463	-74,989	-3,219	-14,771	-21,746

5.1.1.2 Alternatives

EPA estimated the GHG emissions impacts associated with the Proposal and Alternative 2 minus 10 standards, including impacts on tailpipe emissions from light-duty cars and trucks and the upstream emissions associated with the fuels used to power those vehicles (both at the refinery and the electricity generating unit). The tailpipe emissions of CO_2 are estimated internal to the model based on the policy scenario(s) being run (as controlled via the scenarios input file) and the projected compliance pathway which impacts the projected technology mix. The tailpipe emissions of CH_4 and N_2O make use of vehicle emission factors estimated by EPA's MOVES model.[b,4,5] The upstream emissions are then calculated using emission factors applied to the gallons of liquid fuels projected to be consumed and the kilowatt hours of electricity projected to be consumed. The upstream emission factors used in this final rule have been updated since EPA's proposed rule. The updated upstream emission factors are identical to those used in the recent NHTSA CAFE proposal and were generated using the DOE/Argonne GREET model.[6]

[b] EPA used identical CH4 and N2O vehicle tailpipe emission factors to those used by NHTSA in their August CAFE NPRM. See 86 FR 49602.

Table 5-2: Impacts on GHG Emissions under the Proposal Standards Relative to the No Action Scenario

Year	CO_2 Upstream (MMT)	CH_4 Upstream (metric tons)	N_2O Upstream (metric tons)	CO_2 Tailpipe (MMT)	CH_4 Tailpipe (metric tons)	N_2O Tailpipe (metric tons)
2023	0	-3,350	-83	-4	-11	-24
2024	1	-6,787	-163	-8	-22	-51
2025	2	-12,403	-294	-14	-39	-94
2026	2	-18,942	-444	-21	-55	-134
2027	2	-27,167	-629	-29	-80	-181
2028	2	-35,787	-823	-37	-107	-229
2029	2	-43,622	-999	-44	-138	-276
2030	2	-51,167	-1,169	-52	-170	-321
2031	2	-58,239	-1,327	-59	-200	-362
2032	2	-65,114	-1,481	-65	-230	-405
2033	2	-71,682	-1,629	-72	-262	-446
2034	3	-77,674	-1,766	-77	-291	-484
2035	3	-83,132	-1,891	-83	-374	-519
2036	3	-87,868	-2,001	-87	-402	-551
2037	3	-91,701	-2,091	-91	-426	-578
2038	3	-95,015	-2,168	-94	-447	-601
2039	3	-97,966	-2,235	-97	-465	-621
2040	3	-100,475	-2,293	-99	-481	-639
2041	3	-102,563	-2,341	-101	-494	-654
2042	3	-104,143	-2,376	-103	-505	-665
2043	3	-105,813	-2,415	-104	-516	-678
2044	2	-107,247	-2,448	-105	-526	-689
2045	2	-108,374	-2,474	-106	-533	-697
2046	2	-109,333	-2,496	-106	-540	-704
2047	2	-110,095	-2,512	-107	-545	-710
2048	2	-110,800	-2,528	-107	-550	-716
2049	1	-112,412	-2,543	-107	-555	-723
2050	1	-114,017	-2,558	-108	-560	-729
Sum	59	-2,112,887	-48,177	-2,086	-9,525	-13,484

Table 5-3: Impacts on GHG Emissions under the Alternative 2 minus 10 Standards Relative to the No Action Scenario

Year	CO_2 Upstream (MMT)	CH_4 Upstream (metric tons)	N_2O Upstream (metric tons)	CO_2 Tailpipe (MMT)	CH_4 Tailpipe (metric tons)	N_2O Tailpipe (metric tons)
2023	0	-7,751	-180	-8	-19	-40
2024	1	-14,238	-328	-15	-34	-80
2025	1	-22,073	-506	-23	-54	-130
2026	2	-32,434	-748	-33	-85	-202
2027	2	-44,564	-1,027	-45	-121	-277
2028	2	-57,775	-1,332	-58	-169	-364
2029	3	-69,705	-1,608	-70	-219	-447
2030	3	-81,328	-1,878	-81	-276	-532
2031	3	-92,290	-2,131	-92	-328	-610
2032	4	-102,768	-2,373	-103	-382	-686
2033	4	-112,594	-2,599	-112	-434	-756
2034	4	-121,539	-2,808	-121	-484	-822
2035	5	-129,681	-2,999	-129	-623	-882
2036	5	-136,890	-3,170	-137	-672	-938
2037	5	-142,869	-3,312	-143	-714	-986
2038	5	-148,053	-3,436	-148	-752	-1,028
2039	5	-152,748	-3,545	-152	-784	-1,065
2040	5	-156,641	-3,637	-156	-813	-1,096
2041	5	-159,903	-3,714	-159	-835	-1,121
2042	5	-162,696	-3,780	-161	-856	-1,145
2043	5	-164,960	-3,833	-163	-873	-1,164
2044	5	-167,076	-3,882	-165	-888	-1,181
2045	4	-168,784	-3,919	-166	-899	-1,194
2046	4	-170,221	-3,951	-167	-908	-1,206
2047	4	-171,604	-3,982	-168	-918	-1,220
2048	3	-172,872	-4,010	-168	-928	-1,234
2049	3	-175,336	-4,031	-169	-936	-1,246
2050	2	-177,862	-4,052	-169	-943	-1,257
Sum	99	-3,317,253	-76,770	-3,282	-15,948	-22,910

The cumulative CO_2 emission reductions relative to the No Action scenario are shown in Figure 5-4.

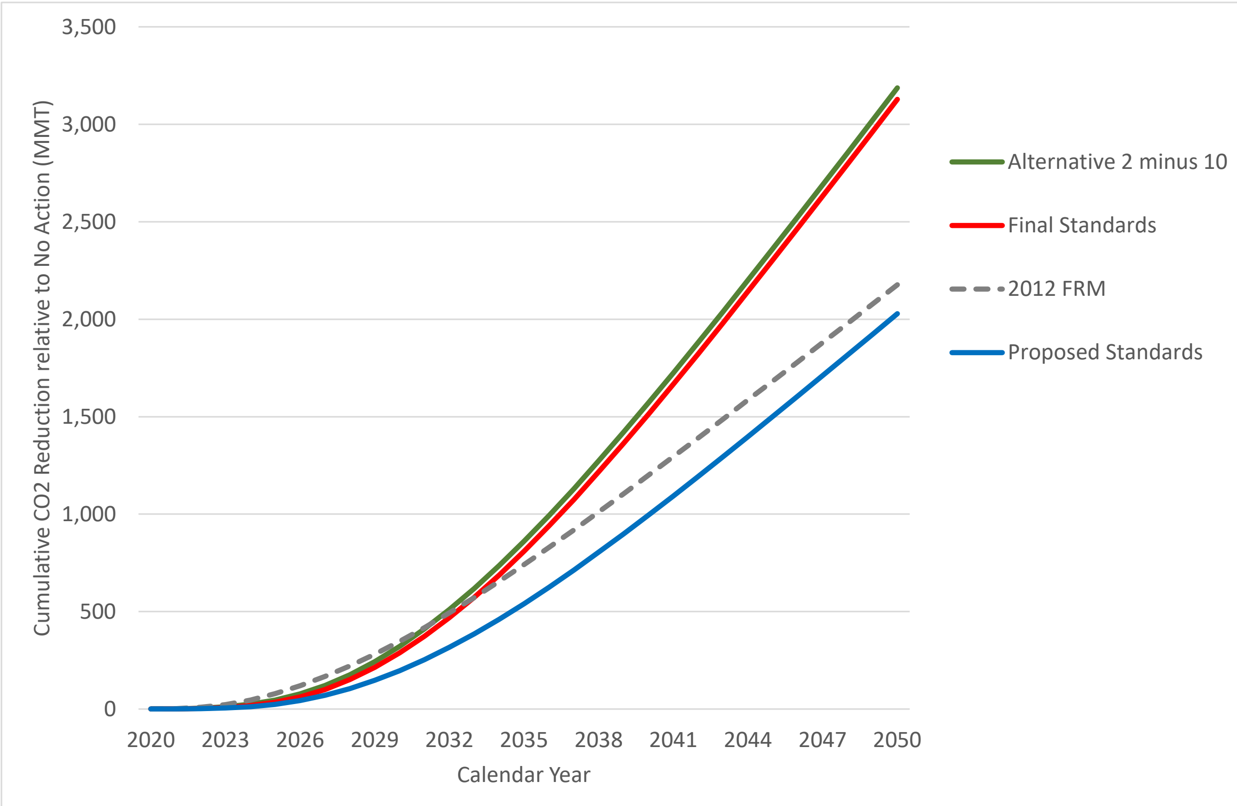

Figure 5-4 Cumulative CO_2 Reductions relative to the No Action scenario (Million Metric Tons CO_2)

5.1.2 <u>Non-Greenhouse Gas Emissions</u>

5.1.2.1 Final Rule

The model runs that EPA conducted estimated the inventories under the Final standards of non-GHG air pollutants resulting from tailpipe emissions from light-duty cars and trucks, and the upstream emissions associated with the fuels used to power those vehicles (both at the refinery and the electricity generating unit).[c] The tailpipe emissions of $PM_{2.5}$, NOx, VOCs, CO and SO_2 are estimated using emission factors from EPA's MOVES model. The tailpipe emission factors used are identical to those used in NHTSA's recent NPRM.[7] The upstream emissions are then calculated using emission factors applied to the gallons of liquid fuels projected to be consumed and the kilowatt hours of electricity projected to be consumed. The upstream emission factors used in this final rule modeling have been updated since EPA's proposed rule. The updated upstream emission factors are identical to those used in the recent NHTSA CAFE proposal and were generated using the DOE/Argonne GREET model.[8] See Figure 5-4 through Figure 5-7 for a comparison of how some of our upstream non-GHG emission factors have changed since the NPRM. See Figure 5-8 for how some of our tailpipe emission factors have changed since the NPRM.

[c] Section V.C of the preamble includes more information on why we were not able to perform air quality modeling for the non-GHG impacts of this rulemaking. We are considering how to project air quality impacts from changes in non-GHG emissions in future LD GHG rulemakings.

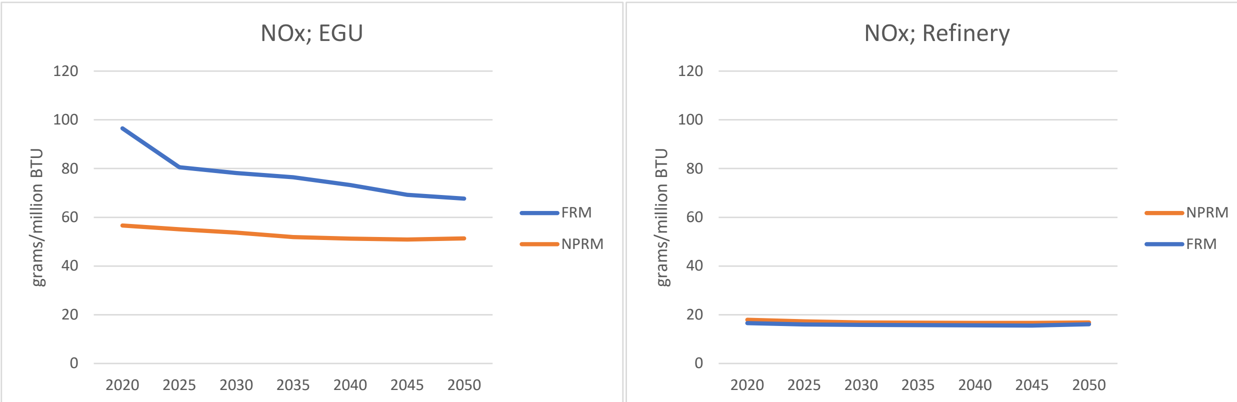

Figure 5-5 Electricity Generating Unit (EGU) and Refinery Emission Factors for NOx

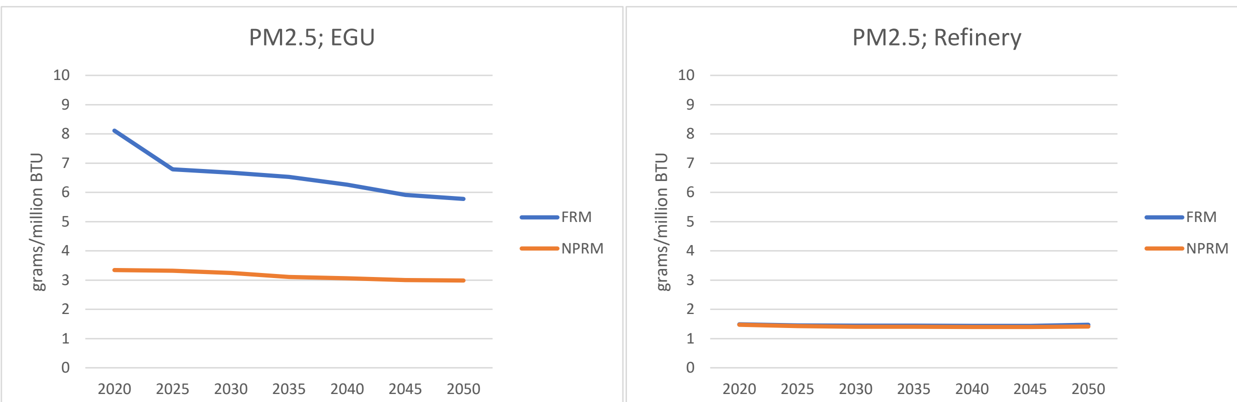

Figure 5-6 Electricity Generating Unit (EGU) and Refinery Emission Factors for $PM_{2.5}$

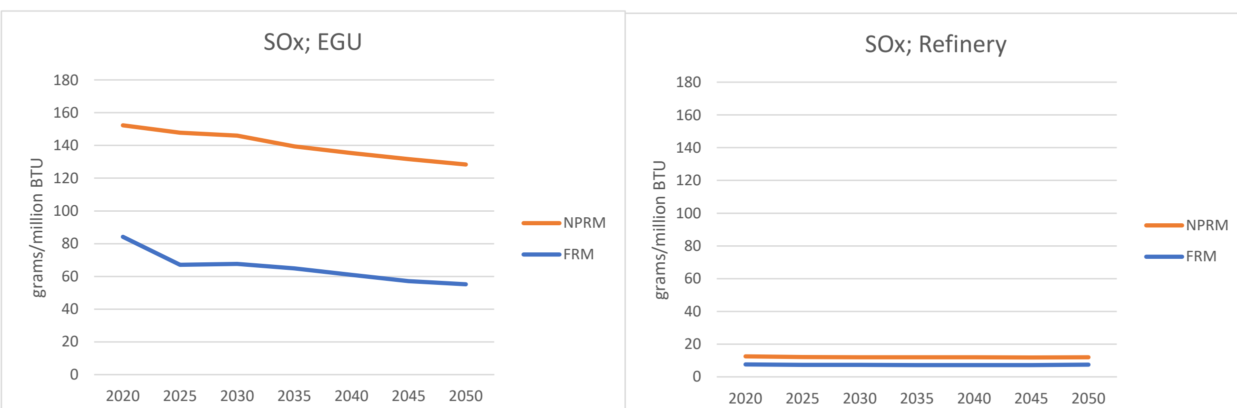

Figure 5-7 Electricity Generating Unit (EGU) and Refinery Emission Factors for SOx

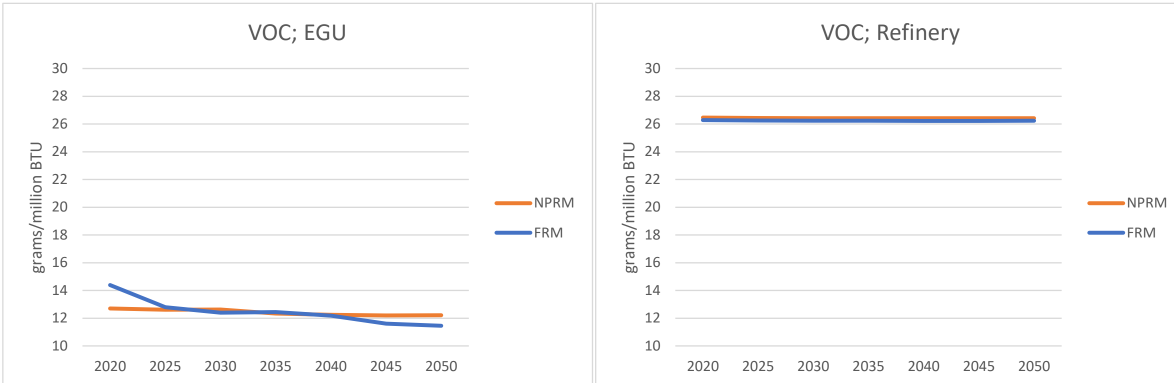

Figure 5-8 Electricity Generating Unit (EGU) and Refinery Emission Factors for VOC

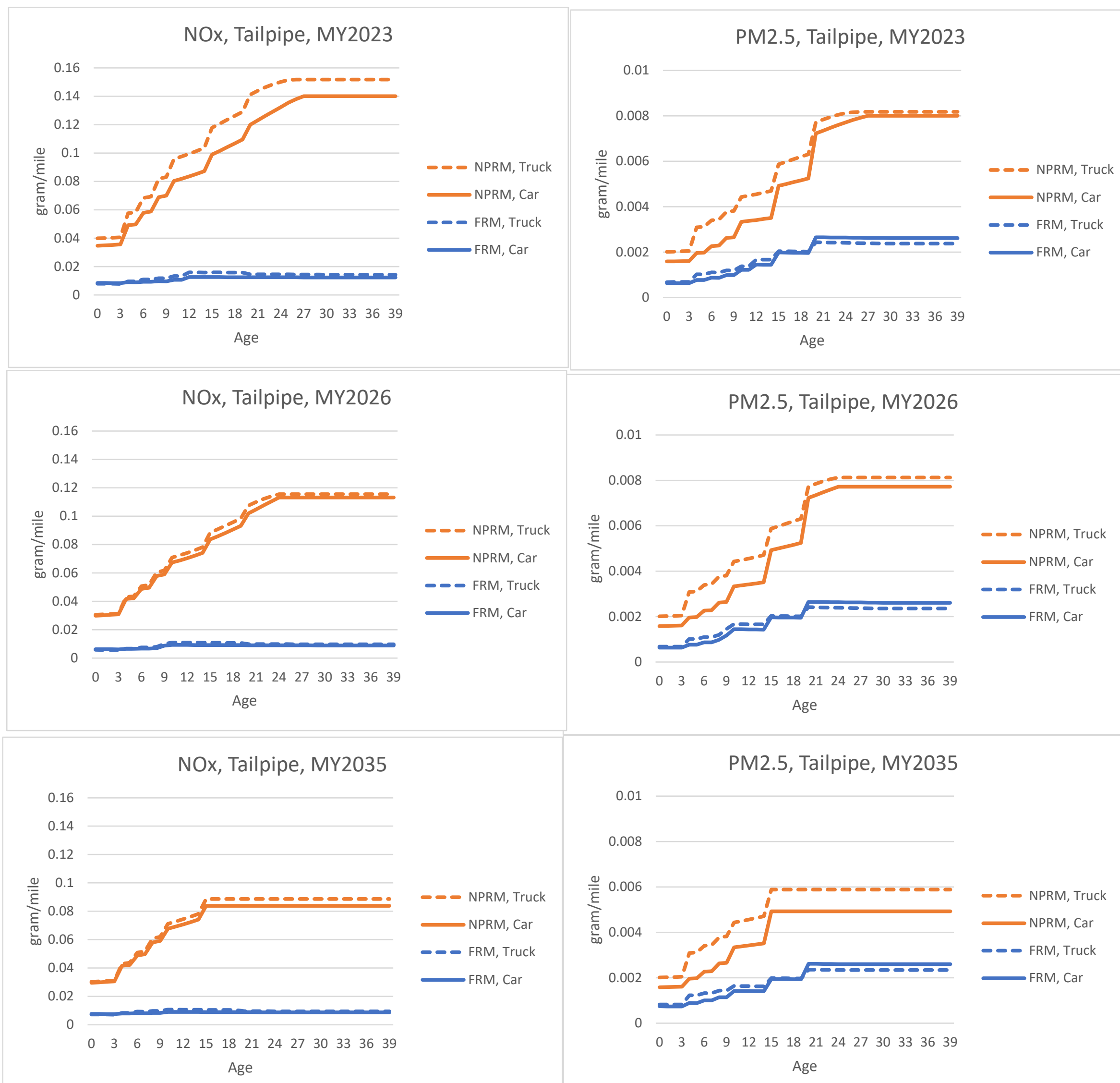

Figure 5-9 Tailpipe Emission Factors for MYs 2023, 2026 and 2035 for NOx and $PM_{2.5}$

Table 5-4: Impacts on Upstream Non-GHG Emissions Under the Final Standards Relative to the No Action Scenario

	$PM_{2.5}$ (US tons)		NOx (US tons)		SO_2 (US tons)		VOC (US tons)		CO (US tons)	
Year	EGU	Refinery	EGU	Refinery	EGU	Refinery	EGU	Refinery	EGU	Refinery
2023	111	-110	1,320	-1,226	1,154	-558	197	-1,941	699	-688
2024	244	-222	2,898	-2,471	2,512	-1,118	437	-3,899	1,551	-1,392
2025	417	-380	4,957	-4,231	4,260	-1,911	756	-6,713	2,681	-2,391
2026	640	-595	7,601	-6,607	6,473	-2,984	1,174	-10,560	4,158	-3,745
2027	857	-842	10,172	-9,329	8,577	-4,214	1,592	-15,010	5,632	-5,302
2028	1,067	-1,099	12,667	-12,161	10,565	-5,494	2,011	-19,700	7,105	-6,930
2029	1,291	-1,344	15,275	-14,850	12,836	-6,731	2,425	-24,132	8,571	-8,475
2030	1,506	-1,581	17,773	-17,440	15,045	-7,930	2,821	-28,421	9,976	-9,968
2031	1,704	-1,802	20,057	-19,858	17,106	-9,057	3,183	-32,456	11,262	-11,368
2032	1,898	-2,018	22,283	-22,197	19,147	-10,154	3,536	-36,385	12,517	-12,729
2033	2,078	-2,219	24,324	-24,373	21,060	-11,181	3,859	-40,068	13,669	-14,000
2034	2,243	-2,408	26,254	-26,430	22,645	-12,139	4,187	-43,508	14,818	-15,196
2035	2,389	-2,579	27,964	-28,286	24,029	-13,006	4,483	-46,623	15,853	-16,278
2036	2,521	-2,732	29,497	-29,940	25,249	-13,781	4,753	-49,415	16,797	-17,247
2037	2,636	-2,864	30,849	-31,373	26,304	-14,456	4,997	-51,846	17,646	-18,089
2038	2,735	-2,979	31,996	-32,607	27,175	-15,040	5,210	-53,952	18,384	-18,819
2039	2,806	-3,077	32,826	-33,659	27,772	-15,529	5,368	-55,763	18,930	-19,443
2040	2,862	-3,159	33,480	-34,535	28,215	-15,938	5,498	-57,286	19,380	-19,966
2041	2,900	-3,226	33,932	-35,240	28,481	-16,267	5,596	-58,526	19,716	-20,391
2042	2,924	-3,277	34,212	-35,780	28,598	-16,520	5,667	-59,496	19,955	-20,721
2043	2,939	-3,318	34,384	-36,211	28,621	-16,722	5,721	-60,285	20,134	-20,989
2044	2,933	-3,349	34,312	-36,539	28,528	-16,869	5,719	-60,881	20,122	-21,179
2045	2,921	-3,372	34,165	-36,788	28,371	-16,979	5,704	-61,342	20,067	-21,323
2046	2,905	-3,389	33,977	-36,973	28,180	-17,058	5,682	-61,694	19,988	-21,430
2047	2,883	-3,399	33,714	-37,083	27,927	-17,103	5,648	-61,923	19,866	-21,495
2048	2,860	-3,407	33,436	-37,170	27,660	-17,137	5,612	-62,111	19,734	-21,545
2049	2,851	-3,431	33,350	-37,475	27,512	-17,308	5,606	-62,238	19,706	-21,633
2050	2,841	-3,454	33,249	-37,769	27,351	-17,473	5,597	-62,347	19,669	-21,713

Table 5-5: Estimated Non-GHG Emission Impacts of the Final Standards Relative to the No Action Scenario

	Upstream Emissions (US tons)					Tailpipe Emissions (US tons)				
Year	$PM_{2.5}$	NOx	SO_2	VOC	CO	$PM_{2.5}$	NOx	SO_2	VOC	CO
2023	1	94	596	-1,744	12	7	717	-37	1,003	6,505
2024	22	427	1,394	-3,462	159	9	1,173	-77	1,693	10,048
2025	37	726	2,349	-5,957	290	8	1,645	-133	2,424	13,248
2026	45	994	3,490	-9,386	413	4	2,090	-208	3,149	15,356
2027	15	843	4,363	-13,418	331	-4	2,399	-295	3,702	15,150
2028	-32	505	5,072	-17,689	174	-21	2,383	-386	3,820	9,475
2029	-53	425	6,105	-21,707	96	-46	2,108	-471	3,566	-474
2030	-75	333	7,115	-25,601	8	-77	1,588	-554	2,962	-14,786
2031	-99	199	8,049	-29,273	-106	-106	1,167	-633	2,469	-27,521
2032	-120	85	8,994	-32,849	-212	-137	699	-709	1,896	-41,484
2033	-141	-49	9,878	-36,209	-331	-168	228	-780	1,287	-55,715
2034	-165	-177	10,506	-39,321	-377	-199	-241	-846	666	-70,103
2035	-190	-322	11,023	-42,140	-425	-287	-1,250	-906	-2,905	-92,848
2036	-211	-443	11,468	-44,661	-449	-321	-1,693	-959	-3,647	-106,860
2037	-228	-524	11,848	-46,849	-444	-353	-2,079	-1,006	-4,323	-119,740
2038	-244	-610	12,135	-48,742	-435	-383	-2,419	-1,046	-4,946	-131,691
2039	-271	-833	12,243	-50,395	-512	-409	-2,698	-1,081	-5,495	-142,121
2040	-297	-1,055	12,277	-51,788	-586	-434	-2,943	-1,110	-5,993	-151,549
2041	-325	-1,308	12,214	-52,930	-674	-455	-3,138	-1,134	-6,422	-159,628
2042	-353	-1,568	12,078	-53,829	-766	-473	-3,290	-1,153	-6,784	-166,420
2043	-379	-1,827	11,899	-54,564	-855	-490	-3,416	-1,168	-7,117	-172,314
2044	-415	-2,227	11,659	-55,162	-1,057	-503	-3,508	-1,178	-7,402	-177,017
2045	-451	-2,624	11,392	-55,638	-1,256	-514	-3,575	-1,185	-7,660	-180,783
2046	-483	-2,995	11,122	-56,012	-1,442	-523	-3,633	-1,191	-7,914	-184,085
2047	-516	-3,368	10,823	-56,274	-1,629	-531	-3,675	-1,194	-8,135	-186,783
2048	-548	-3,734	10,523	-56,499	-1,811	-538	-3,708	-1,196	-8,332	-189,005
2049	-580	-4,124	10,204	-56,633	-1,926	-543	-3,729	-1,197	-8,488	-190,712
2050	-613	-4,519	9,878	-56,749	-2,044	-547	-3,745	-1,198	-8,619	-192,095

5.1.2.2 Alternatives

The model runs that EPA conducted estimated the inventories under the Proposal and Alternative 2 minus 10 standards of non-GHG air pollutants resulting from tailpipe emissions from light-duty cars and trucks, and the upstream emissions associated with the fuels used to power those vehicles (both at the refinery and the electricity generating unit). The tailpipe emissions of $PM_{2.5}$, NOx, VOCs, CO and SO_2 are estimated using emission factors from EPA's MOVES model. The tailpipe emission factors used are identical to those used in NHTSA's recent NPRM.[9] The upstream emissions are then calculated using emission factors applied to the gallons of liquid fuels projected to be consumed and the kilowatt hours of electricity projected to be consumed. The upstream emission factors used in this final rule modeling have been updated since EPA's proposed rule. The updated upstream emission factors are identical to those used in the recent NHTSA CAFE proposal and were generated using the DOE/Argonne GREET model.[10]

Table 5-6: Impacts on Upstream Non-GHG Emissions under the Proposal Standards Relative to the No Action Scenario

	$PM_{2.5}$ (US tons)		NOx (US tons)		SO_2 (US tons)		VOC (US tons)		CO (US tons)	
Year	EGU	Refinery	EGU	Refinery	EGU	Refinery	EGU	Refinery	EGU	Refinery
2023	100	-81	1,190	-902	1,040	-409	177	-1,430	630	-506
2024	206	-162	2,450	-1,811	2,124	-817	369	-2,851	1,311	-1,021
2025	350	-288	4,163	-3,209	3,578	-1,446	635	-5,079	2,252	-1,815
2026	483	-424	5,735	-4,707	4,884	-2,120	886	-7,501	3,137	-2,670
2027	618	-585	7,337	-6,482	6,187	-2,921	1,148	-10,398	4,063	-3,687
2028	744	-748	8,825	-8,282	7,361	-3,733	1,401	-13,377	4,950	-4,724
2029	879	-903	10,399	-9,976	8,738	-4,512	1,651	-16,165	5,835	-5,698
2030	1,007	-1,051	11,889	-11,591	10,065	-5,259	1,887	-18,837	6,674	-6,630
2031	1,123	-1,187	13,223	-13,077	11,277	-5,951	2,098	-21,315	7,425	-7,492
2032	1,240	-1,321	14,553	-14,527	12,506	-6,631	2,309	-23,748	8,175	-8,337
2033	1,352	-1,449	15,831	-15,909	13,706	-7,283	2,512	-26,086	8,896	-9,146
2034	1,452	-1,567	17,001	-17,197	14,664	-7,882	2,711	-28,236	9,596	-9,895
2035	1,541	-1,674	18,039	-18,360	15,501	-8,425	2,892	-30,188	10,227	-10,574
2036	1,619	-1,768	18,950	-19,374	16,221	-8,900	3,054	-31,899	10,791	-11,169
2037	1,683	-1,844	19,699	-20,198	16,796	-9,288	3,191	-33,299	11,267	-11,655
2038	1,737	-1,910	20,326	-20,904	17,263	-9,623	3,310	-34,507	11,678	-12,074
2039	1,773	-1,964	20,747	-21,486	17,553	-9,894	3,392	-35,513	11,964	-12,420
2040	1,803	-2,011	21,096	-21,979	17,778	-10,123	3,464	-36,374	12,211	-12,716
2041	1,824	-2,048	21,340	-22,374	17,912	-10,308	3,520	-37,074	12,400	-12,955
2042	1,834	-2,074	21,456	-22,649	17,935	-10,437	3,554	-37,576	12,515	-13,126
2043	1,848	-2,104	21,620	-22,955	17,997	-10,580	3,597	-38,131	12,660	-13,315
2044	1,849	-2,125	21,622	-23,190	17,977	-10,687	3,604	-38,561	12,681	-13,451
2045	1,842	-2,140	21,544	-23,351	17,890	-10,759	3,597	-38,867	12,654	-13,544
2046	1,835	-2,153	21,455	-23,483	17,795	-10,817	3,588	-39,122	12,622	-13,620
2047	1,823	-2,160	21,314	-23,567	17,655	-10,853	3,571	-39,296	12,559	-13,669
2048	1,811	-2,167	21,175	-23,642	17,517	-10,884	3,554	-39,456	12,498	-13,713
2049	1,812	-2,188	21,201	-23,896	17,490	-11,021	3,564	-39,641	12,528	-13,802
2050	1,812	-2,208	21,211	-24,142	17,448	-11,154	3,571	-39,814	12,548	-13,887

Table 5-7: Impacts on Non-GHG Emissions under the Proposal Standards Relative to the No Action Scenario

	Upstream Emissions (US tons)					Tailpipe Emissions (US tons)				
Year	$PM_{2.5}$	NOx	SO_2	VOC	CO	$PM_{2.5}$	NOx	SO_2	VOC	CO
2023	19	288	630	-1,252	124	5	551	-27	778	4,643
2024	44	640	1,307	-2,482	290	7	948	-57	1,380	7,860
2025	62	955	2,132	-4,444	437	4	1,246	-102	1,849	9,188
2026	59	1,028	2,764	-6,615	467	3	1,584	-150	2,402	11,572
2027	33	855	3,265	-9,250	376	-7	1,588	-207	2,485	8,257
2028	-5	543	3,628	-11,976	226	-20	1,512	-265	2,467	3,668
2029	-24	423	4,226	-14,514	137	-37	1,286	-320	2,233	-3,534
2030	-43	298	4,806	-16,950	43	-56	932	-372	1,810	-12,887
2031	-64	146	5,326	-19,216	-68	-74	652	-421	1,473	-21,185
2032	-81	26	5,875	-21,438	-162	-93	348	-468	1,090	-30,146
2033	-96	-78	6,423	-23,574	-249	-113	39	-514	682	-39,590
2034	-115	-196	6,782	-25,525	-299	-132	-257	-556	279	-48,723
2035	-133	-321	7,076	-27,296	-347	-187	-901	-593	-1,997	-63,422
2036	-148	-424	7,321	-28,845	-377	-207	-1,169	-626	-2,452	-71,908
2037	-161	-500	7,508	-30,109	-387	-225	-1,394	-653	-2,855	-79,513
2038	-173	-578	7,640	-31,198	-395	-242	-1,589	-677	-3,227	-86,536
2039	-191	-740	7,659	-32,121	-456	-257	-1,746	-696	-3,549	-92,586
2040	-207	-883	7,654	-32,909	-505	-272	-1,885	-713	-3,851	-98,171
2041	-224	-1,033	7,604	-33,554	-556	-284	-1,995	-726	-4,101	-102,802
2042	-240	-1,193	7,498	-34,022	-611	-294	-2,078	-736	-4,311	-106,641
2043	-256	-1,335	7,416	-34,534	-655	-305	-2,160	-746	-4,533	-110,466
2044	-277	-1,568	7,291	-34,958	-770	-313	-2,222	-753	-4,722	-113,561
2045	-298	-1,807	7,132	-35,270	-890	-320	-2,265	-758	-4,895	-115,937
2046	-318	-2,028	6,978	-35,534	-998	-326	-2,305	-761	-5,047	-118,042
2047	-338	-2,253	6,803	-35,726	-1,110	-332	-2,335	-763	-5,182	-119,820
2048	-356	-2,467	6,633	-35,902	-1,215	-336	-2,360	-765	-5,305	-121,407
2049	-376	-2,694	6,469	-36,078	-1,274	-340	-2,384	-768	-5,415	-122,928
2050	-396	-2,932	6,294	-36,243	-1,340	-344	-2,403	-770	-5,509	-124,246

Table 5-8: Impacts on Upstream Non-GHG Emissions under the Alternative 2 minus 10 Standards Relative to the No Action Scenario

	$PM_{2.5}$ (US tons)		NOx (US tons)		SO_2 (US tons)		VOC (US tons)		CO (US tons)	
Year	EGU	Refinery	EGU	Refinery	EGU	Refinery	EGU	Refinery	EGU	Refinery
2023	165	-165	1,967	-1,844	1,719	-840	293	-2,915	1,042	-1,033
2024	317	-305	3,766	-3,402	3,264	-1,543	568	-5,383	2,015	-1,914
2025	475	-468	5,651	-5,202	4,857	-2,356	862	-8,272	3,057	-2,937
2026	690	-685	8,193	-7,610	6,977	-3,444	1,265	-12,181	4,482	-4,310
2027	899	-927	10,678	-10,280	9,004	-4,652	1,671	-16,559	5,913	-5,838
2028	1,114	-1,187	13,220	-13,140	11,027	-5,945	2,099	-21,305	7,415	-7,484
2029	1,341	-1,431	15,879	-15,818	13,343	-7,179	2,520	-25,724	8,909	-9,022
2030	1,565	-1,669	18,472	-18,420	15,638	-8,386	2,932	-30,043	10,369	-10,523
2031	1,771	-1,891	20,846	-20,840	17,780	-9,516	3,308	-34,088	11,706	-11,925
2032	1,966	-2,102	23,079	-23,130	19,832	-10,593	3,662	-37,945	12,965	-13,257
2033	2,145	-2,299	25,118	-25,249	21,747	-11,597	3,985	-41,543	14,115	-14,497
2034	2,308	-2,480	27,012	-27,228	23,299	-12,519	4,308	-44,855	15,246	-15,648
2035	2,453	-2,646	28,707	-29,020	24,668	-13,357	4,602	-47,867	16,275	-16,694
2036	2,583	-2,793	30,229	-30,615	25,876	-14,106	4,871	-50,562	17,214	-17,628
2037	2,691	-2,916	31,492	-31,938	26,853	-14,731	5,101	-52,813	18,013	-18,408
2038	2,783	-3,022	32,564	-33,078	27,657	-15,272	5,302	-54,765	18,710	-19,083
2039	2,848	-3,111	33,320	-34,037	28,190	-15,718	5,448	-56,422	19,215	-19,653
2040	2,896	-3,185	33,881	-34,818	28,553	-16,084	5,564	-57,796	19,612	-20,121
2041	2,928	-3,244	34,258	-35,442	28,754	-16,377	5,650	-58,911	19,905	-20,499
2042	2,955	-3,294	34,574	-35,973	28,901	-16,627	5,727	-59,873	20,167	-20,824
2043	2,972	-3,334	34,762	-36,381	28,936	-16,820	5,784	-60,632	20,355	-21,078
2044	2,970	-3,365	34,741	-36,719	28,884	-16,972	5,790	-61,248	20,374	-21,274
2045	2,959	-3,387	34,605	-36,956	28,737	-17,077	5,777	-61,694	20,326	-21,411
2046	2,945	-3,404	34,439	-37,140	28,563	-17,157	5,759	-62,052	20,260	-21,517
2047	2,933	-3,421	34,303	-37,326	28,414	-17,237	5,747	-62,412	20,213	-21,625
2048	2,921	-3,436	34,153	-37,489	28,253	-17,307	5,732	-62,731	20,157	-21,720
2049	2,923	-3,468	34,199	-37,876	28,212	-17,516	5,748	-62,997	20,208	-21,853
2050	2,928	-3,500	34,263	-38,270	28,185	-17,727	5,768	-63,260	20,269	-21,991

Table 5-9: Impacts on Non-GHG Emissions under the Alternative 2 minus 10 Standards Relative to the No Action Scenario

	Upstream Emissions (US tons)					Tailpipe Emissions (US tons)				
	$PM_{2.5}$	NOx	SO_2	VOC	CO	$PM_{2.5}$	NOx	SO_2	VOC	CO
2023	0	123	878	-2,622	9	13	1,252	-55	1,752	11,518
2024	12	364	1,721	-4,815	101	19	2,004	-105	2,902	18,564
2025	8	449	2,501	-7,410	119	17	2,365	-162	3,509	20,694
2026	4	583	3,534	-10,915	172	7	2,572	-238	3,910	19,264
2027	-28	398	4,352	-14,888	74	-3	2,780	-323	4,332	17,328
2028	-73	80	5,082	-19,206	-69	-25	2,632	-415	4,272	9,005
2029	-90	61	6,164	-23,203	-113	-51	2,297	-500	3,941	-2,175
2030	-105	52	7,251	-27,111	-154	-86	1,694	-583	3,226	-18,312
2031	-121	7	8,264	-30,780	-219	-117	1,213	-661	2,653	-32,396
2032	-137	-50	9,240	-34,282	-293	-150	693	-735	2,002	-47,700
2033	-153	-131	10,151	-37,557	-382	-183	178	-805	1,322	-63,181
2034	-173	-217	10,780	-40,548	-402	-216	-324	-868	643	-78,463
2035	-193	-313	11,311	-43,265	-419	-308	-1,402	-926	-3,144	-102,406
2036	-210	-386	11,770	-45,691	-414	-343	-1,867	-978	-3,924	-116,830
2037	-224	-446	12,122	-47,712	-394	-375	-2,259	-1,021	-4,620	-129,816
2038	-239	-514	12,386	-49,462	-373	-405	-2,602	-1,058	-5,269	-142,066
2039	-263	-717	12,472	-50,974	-438	-432	-2,881	-1,090	-5,832	-152,616
2040	-289	-937	12,469	-52,232	-509	-456	-3,124	-1,115	-6,323	-161,876
2041	-316	-1,184	12,377	-53,261	-593	-477	-3,315	-1,136	-6,747	-169,779
2042	-339	-1,399	12,274	-54,145	-657	-496	-3,474	-1,154	-7,133	-176,790
2043	-362	-1,619	12,116	-54,848	-723	-512	-3,604	-1,168	-7,500	-182,886
2044	-395	-1,978	11,912	-55,458	-900	-526	-3,702	-1,178	-7,812	-187,838
2045	-428	-2,351	11,660	-55,917	-1,085	-537	-3,772	-1,185	-8,072	-191,655
2046	-459	-2,702	11,406	-56,293	-1,257	-548	-3,836	-1,190	-8,334	-195,157
2047	-488	-3,023	11,177	-56,665	-1,412	-558	-3,894	-1,195	-8,585	-198,407
2048	-515	-3,336	10,946	-56,999	-1,562	-566	-3,944	-1,200	-8,822	-201,332
2049	-544	-3,677	10,696	-57,248	-1,646	-574	-3,982	-1,203	-9,014	-203,699
2050	-572	-4,007	10,458	-57,492	-1,722	-580	-4,016	-1,208	-9,191	-205,912

5.2 Projected Fuel Consumption

5.2.1 Final Rule

The revised standards will reduce not only greenhouse gas emissions but also fuel consumption. Reducing fuel consumption is one of, although not the only, means of reducing greenhouse gas emissions from the transportation fleet.

Table 5-10 shows the estimated fuel consumption changes, including rebound effects, credit usage and advanced technology multiplier use, under the final standards relative to the no action scenario.

Table 5-10: Impacts on Fuel Consumption for the Final Standards Relative to the No Action Scenario

Year	Gasoline Equivalents (Million Gallons)	% of 2020 US Gasoline Consumption	Oil (Million BBL)	Electricity (Gigawatt hours)	% of 2020 US Electricity Consumption
2023	-582	-0.5%	-11	3,631	0.1%
2024	-1,197	-1.0%	-23	8,241	0.2%
2025	-2,067	-1.7%	-39	14,593	0.4%
2026	-3,245	-2.6%	-61	23,196	0.6%
2027	-4,603	-3.7%	-87	32,224	0.8%
2028	-6,031	-4.9%	-114	41,712	1.1%
2029	-7,376	-6.0%	-139	50,609	1.3%
2030	-8,680	-7.0%	-164	59,241	1.6%
2031	-9,906	-8.0%	-187	67,266	1.8%
2032	-11,100	-9.0%	-209	75,194	2.0%
2033	-12,219	-9.9%	-231	82,594	2.2%
2034	-13,260	-10.7%	-250	89,541	2.4%
2035	-14,203	-11.5%	-268	95,798	2.5%
2036	-15,046	-12.2%	-284	101,503	2.7%
2037	-15,781	-12.8%	-298	106,634	2.8%
2038	-16,417	-13.3%	-310	111,098	2.9%
2039	-16,964	-13.7%	-320	114,939	3.0%
2040	-17,424	-14.1%	-329	118,225	3.1%
2041	-17,798	-14.4%	-336	120,847	3.2%
2042	-18,091	-14.6%	-341	122,895	3.2%
2043	-18,329	-14.8%	-346	124,591	3.3%
2044	-18,494	-14.9%	-349	125,718	3.3%
2045	-18,620	-15.0%	-351	126,590	3.3%
2046	-18,714	-15.1%	-353	127,333	3.4%
2047	-18,772	-15.2%	-354	127,808	3.4%
2048	-18,818	-15.2%	-355	128,233	3.4%
2049	-18,842	-15.2%	-356	128,458	3.4%
2050	-18,860	-15.2%	-356	128,625	3.4%
Sum	-361,438		-6,821	2,457,336	

Notes:
The CCEMS effects reports (i.e., the model output files) report all liquid fuels as gasoline equivalents; to determine barrels of oil, the gasoline equivalents have been treated as retail gasoline having 90 percent pure gasoline which have then been adjusted using the ratio of the energy densities of pure gasoline to oil (114,200/129,670 both in BTU/gallon, GREET 2017) which is then divided by 42 gallons in a barrel of oil; according to the Energy Information Administration (EIA), US gasoline consumption in 2020 was 123.73 billion gallons, roughly 16 percent less (due to the coronavirus pandemic) than the highest consumption on record (2018).[11] According to the Department of Energy, there are 33.7 kWh of electricity per gallon gasoline equivalent, the metric reported by CCEMS for electricity consumption and used here to convert to kWh. According to EIA, the US consumed 3,800,000 gigawatt hours of electricity in 2020.[12]

5.2.2 Alternatives

Table 5-11and Table 5-12 show the estimated fuel consumption changes, including rebound effects, credit usage and advanced technology multiplier use, under the Proposal and Alternative 2 minus 10 standards, respectively, relative to the no action scenario.

Table 5-11: Impacts on Fuel Consumption for the Proposal Standards Relative to the No Action Scenario

Year	Gasoline Equivalents (Million Gallons)	% of 2020 US Gasoline Consumption	Oil (Million BBL)	Electricity (Gigawatt hours)	% of 2020 US Electricity Consumption
2023	-429	-0.3%	-8	3,272	0.1%
2024	-883	-0.7%	-17	6,967	0.2%
2025	-1,576	-1.3%	-30	12,256	0.3%
2026	-2,325	-1.9%	-44	17,501	0.5%
2027	-3,216	-2.6%	-61	23,243	0.6%
2028	-4,130	-3.3%	-78	29,062	0.8%
2029	-4,982	-4.0%	-94	34,452	0.9%
2030	-5,800	-4.7%	-109	39,631	1.0%
2031	-6,558	-5.3%	-124	44,346	1.2%
2032	-7,303	-5.9%	-138	49,111	1.3%
2033	-8,017	-6.5%	-151	53,754	1.4%
2034	-8,671	-7.0%	-164	57,983	1.5%
2035	-9,265	-7.5%	-175	61,799	1.6%
2036	-9,784	-7.9%	-185	65,210	1.7%
2037	-10,208	-8.3%	-193	68,090	1.8%
2038	-10,575	-8.5%	-200	70,575	1.9%
2039	-10,880	-8.8%	-205	72,643	1.9%
2040	-11,141	-9.0%	-210	74,492	2.0%
2041	-11,352	-9.2%	-214	76,002	2.0%
2042	-11,504	-9.3%	-217	77,073	2.0%
2043	-11,672	-9.4%	-220	78,341	2.1%
2044	-11,787	-9.5%	-222	79,224	2.1%
2045	-11,866	-9.6%	-224	79,828	2.1%
2046	-11,931	-9.6%	-225	80,407	2.1%
2047	-11,971	-9.7%	-226	80,800	2.1%
2048	-12,008	-9.7%	-227	81,211	2.1%
2049	-12,051	-9.7%	-227	81,663	2.1%
2050	-12,089	-9.8%	-228	82,053	2.2%
Sum	-233,975		-4,416	1,580,986	
Notes: See prior table.					

Table 5-12: Impacts on Fuel Consumption for Alternative 2 minus 10 Relative to the No Action Scenario

Year	Gasoline Equivalents (Million Gallons)	% of 2020 US Gasoline Consumption	Oil (Million BBL)	Electricity (Gigawatt hours)	% of 2020 US Electricity Consumption
2023	-873	-0.7%	-16	5,409	0.1%
2024	-1,638	-1.3%	-31	10,708	0.3%
2025	-2,528	-2.0%	-48	16,637	0.4%
2026	-3,721	-3.0%	-70	25,003	0.7%
2027	-5,055	-4.1%	-95	33,826	0.9%
2028	-6,497	-5.3%	-123	43,535	1.1%
2029	-7,836	-6.3%	-148	52,607	1.4%
2030	-9,145	-7.4%	-173	61,574	1.6%
2031	-10,370	-8.4%	-196	69,915	1.8%
2032	-11,539	-9.3%	-218	77,883	2.0%
2033	-12,629	-10.2%	-238	85,290	2.2%
2034	-13,631	-11.0%	-257	92,126	2.4%
2035	-14,541	-11.8%	-274	98,345	2.6%
2036	-15,354	-12.4%	-290	104,023	2.7%
2037	-16,033	-13.0%	-303	108,856	2.9%
2038	-16,622	-13.4%	-314	113,069	3.0%
2039	-17,123	-13.8%	-323	116,668	3.1%
2040	-17,530	-14.2%	-331	119,642	3.1%
2041	-17,860	-14.4%	-337	122,006	3.2%
2042	-18,145	-14.7%	-342	124,197	3.3%
2043	-18,369	-14.8%	-347	125,961	3.3%
2044	-18,537	-15.0%	-350	127,288	3.3%
2045	-18,654	-15.1%	-352	128,223	3.4%
2046	-18,746	-15.2%	-354	129,064	3.4%
2047	-18,840	-15.2%	-356	130,040	3.4%
2048	-18,922	-15.3%	-357	130,982	3.4%
2049	-18,985	-15.3%	-358	131,726	3.5%
2050	-19,055	-15.4%	-360	132,547	3.5%
Sum	-368,780		-6,960	2,517,150	
Notes: See prior table.					

5.3 Projected Safety Impacts

EPA has long considered the safety implications of its emission standards. With respect to its light-duty greenhouse gas emission regulations, EPA has historically considered the potential impacts of GHG standards on safety including: the 2010 rule which established the 2012-2016 light-duty vehicle GHG standards, the 2012 rule which previously established 2017-2025 light-duty vehicle GHG standards, the 2017 MTE Proposed Determination and the 2020 SAFE Rulemaking. In addition, section 202(a)(4) of the Clean Air Act specifically prohibits the use of an emission control device, system or element of design that will cause or contribute to an unreasonable risk to public health, welfare, or safety.

The potential relationship between GHG emissions standards and safety is multi-faceted, and can be influenced not only by control technologies, but also by consumer decisions about vehicle ownership and use. EPA has estimated the impacts of this rule on safety by accounting for changes in new vehicle purchase, changes in vehicle scrappage, fleet turnover and VMT, and changes in vehicle weight as an emissions control strategy. Safety impacts relate to changes in the use of vehicles in the fleet, relative mass changes, and the turnover of fleet to newer and safer vehicles fleet turnover have been estimated and considered in the standard setting process.

The GHG emissions standards are attribute-based standards, using vehicle footprint as the attribute. Footprint is defined as a vehicle's wheelbase multiplied by its average track width—in other words, the area enclosed by the points at which the wheels meet the ground. The standards are therefore generally based on a vehicle's size: larger vehicles have numerically higher GHG emissions targets and smaller vehicles have numerically lower GHG emissions targets. Footprint-based standards help to distribute the burden of compliance across all vehicle footprints and across all manufacturers. Manufacturers are not compelled to build vehicles of any particular size or type, and each manufacturer has its own fleetwide standard for its car and truck fleets in each year that reflects the light-duty vehicles it chooses to produce.

Consistent with previous light-duty GHG analyses, EPA assessed the potential of these final MY 2023-2026 standards to affect vehicle safety. EPA applied the same historical relationships between mass, size, and fatality risk that were established and documented in the SAFE rulemaking. These relationships are based on the statistical analysis of historical crash data, which included an analysis performed by using the most recently available crash studies based on data for model years 2007 to 2011. EPA used the findings of this analysis to estimate safety impacts of the modeled mass reductions over the lifetimes of new vehicles in response to MYs 2023-2026 standards. As in initially promulgating the GHG standards, the MTE Proposed Determination and this rule, EPA's assessment is that manufacturers can achieve the MYs 2023-2026 standards while using modest levels of mass reduction as one technology option among many. On the whole, EPA considers safety impacts in the context of all projected health impacts from the rule including public health benefits from the projected reductions in air pollution.

The projected change in risk of fatal and non-fatal injuries is influenced by changes in fleet mix (car/truck share), vehicle scrappage rates, distribution of VMT among vehicles in the fleet and vehicle mass. EPA estimates that these factors together will result in an average 0.06 percent increase (with results from sensitivity cases ranging from a decrease of 0.25 percent to an increase of 0.36 percent) in the annual fatalities per billion miles driven through 2050.[13] In addition to changes in risk, EPA also considered the projected impact of the final standards on the absolute number of fatal and non-fatal injuries. The majority of the fatalities projected would result from the projected increased driving – i.e., people choosing to drive more due to the lower operating costs of more efficient vehicles. Our cost-benefit analysis accounts for both the value of this additional driving and its associated risk, which we assume are considerations in the decision to drive. The risk valuation associated with this increase in driving partially offsets the associated increase in societal costs due to increased fatalities and non-fatal injuries.

This analysis projects that there will be an increase in vehicle miles traveled (VMT) under the revised standards of 304 billion miles compared to the No Action case through 2050 (an increase of about 0.3 percent). EPA estimates that vehicle safety, in terms of risk measured as the total fatalities per the total distance travelled over this period, will remain almost unchanged at 5.012 fatalities per billion miles under the rule, compared to 5.010 fatalities per billion miles for the no-action case. EPA has also estimated, over the same 30-year period, that total fatalities will increase by 1,780, with 1,348 deaths attributed to increased driving and 432 deaths attributed to the increase in fatality risk. In other words, approximately 75 percent of the change in fatalities under these revised standards is due to projected increases in VMT and mobility (i.e., people driving more). Our analysis also considered the increase in non-fatal injuries. Consistent with the SAFE FRM, EPA assumed that non-fatal injuries scale with fatal injuries.

EPA also estimated the societal costs of these safety impacts using assumptions consistent with the SAFE FRM (see Table 10-1). Specifically, we are continuing to use the cost associated with each fatality of $10.4 million. We have also continued to use a scalar of approximately 1.6 applied to fatality costs to estimate non-fatal injury costs. In addition, we have accounted for the driver's inherent valuation of risk when making the decision to drive more due to rebound. This risk valuation partially offsets the fatal and non-fatal injury costs described above, and, consistent with the SAFE FRM, is calculated as 90 percent of the fatal and non-fatal injury costs due to rebound to reflect the fact that consumers do not fully evaluate the risks associated with this additional driving.

References for Chapter 5

[1] U.S. EPA. Overview of EPA's MOtor Vehicle Emission Simulator (MOVES3). EPA-420-R-21-004. March 2021.
[2] 86 FR 49602
[3] U.S. Department of Energy, Argonne National Laboratory, Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model, Last Update: 9 Oct. 2020, https://greet.es.anl.gov/.
[4] U.S. EPA. Overview of EPA's MOtor Vehicle Emission Simulator (MOVES3). EPA-420-R-21-004. March 2021.
[5] 86 FR 49602
[6] U.S. Department of Energy, Argonne National Laboratory, Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model, Last Update: 9 Oct. 2020, https://greet.es.anl.gov/.
[7] 86 FR 49602.
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[10] U.S. Department of Energy, Argonne National Laboratory, Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model, Last Update: 9 Oct. 2020, https://greet.es.anl.gov/.
[11] www.eia.gov/tools/faqs, accessed on 11/5/2021, see US_gasoline_consumption_2020.pdf contained in the docket for this rule.
[12] www.eia.gov/energyexplained/electricity/use-of-electricity.php, accessed on 11/5/2021, see US_electricity_consumption_2020.pdf contained in the docket for this rule.
[13] This range of fatality risk values is based on a sensitivity analysis using the 5% to 95% confidence interval of mass-safety coefficients presented in the SAFE FRM.

Chapter 6: Vehicle Costs, Fuel Savings and Non-Emission Benefits

In this chapter, EPA presents our estimate of the costs, the fuel savings and the non-emission benefits associated with the revised standards.

6.1 Costs

The presentation here summarizes the vehicle level costs associated with the new technologies expected to be added to meet the MY 2023 and later GHG standards, including hardware costs to comply with the A/C credit program. The analysis summarized here also provides costs associated with congestion and noise (see Chapter 3), and for fatalities and non-fatal crashes and includes rebound effects.

For our analysis of safety impacts and how they are reflected in the benefit cost analysis, having used the CCEMS, we have also used the safety-related inputs consistent with the NPRM. For example, we have used the costs associated with fatalities of $10.4 million, as was done in the NPRM and the SAFE FRM. We have also used, as mentioned above, the scaler of approximately 1.6 applied to fatality costs to estimate non-fatal crash costs. In addition, we have offset the fatality costs with a fatality risk value calculated as the fatalities due to rebound driving multiplied by the fatality costs scaled by 90 percent to reflect the fact that consumers do not fully evaluate the risks associated with driving. The same non-fatal crash risk scaler was applied to the fatality risk value to estimate the non-fatal crash risk value. All of this is done exactly as was done in the NPRM and in the SAFE FRM with the exception that, rather than presenting fatality costs and non-fatal crash costs as "Costs" and fatality risk value and non-fatal crash risk value as "Benefits," we have calculated the net of these and present the net result as a "Cost."

6.1.1 Final Rule

Table 6-1: Costs Associated with the Final Program Relative to the No Action Scenario ($Billions of 2018 dollars)

Calendar Year	Foregone Consumer Sales Surplus	Technology Costs	Congestion	Noise	Fatality Costs	Non-fatal Crash Costs	Total Costs
2023	0.029	5.6	0.03	0.00045	0.13	0.23	6.1
2024	0.045	8.9	0.048	0.00075	0.23	0.38	9.6
2025	0.079	13	0.082	0.0013	0.32	0.54	14
2026	0.11	16	0.12	0.002	0.42	0.7	17
2027	0.13	18	0.19	0.0031	0.49	0.82	20
2028	0.12	19	0.26	0.0043	0.51	0.85	20
2029	0.1	17	0.32	0.0054	0.49	0.82	19
2030	0.093	17	0.4	0.0067	0.44	0.73	19
2031	0.093	17	0.46	0.0077	0.41	0.67	19
2032	0.088	17	0.53	0.0088	0.37	0.61	19
2033	0.086	17	0.58	0.0097	0.34	0.55	19
2034	0.082	17	0.64	0.011	0.3	0.49	19
2035	0.078	17	0.68	0.011	0.27	0.44	19
2036	0.074	17	0.73	0.012	0.23	0.38	18
2037	0.071	16	0.76	0.013	0.21	0.34	18
2038	0.068	16	0.79	0.013	0.18	0.3	17
2039	0.066	16	0.81	0.014	0.17	0.27	17
2040	0.063	16	0.84	0.014	0.15	0.25	17
2041	0.061	16	0.86	0.014	0.15	0.24	17
2042	0.06	16	0.87	0.015	0.14	0.23	17
2043	0.058	16	0.88	0.015	0.14	0.22	17
2044	0.057	15	0.89	0.015	0.14	0.22	17
2045	0.057	15	0.89	0.015	0.14	0.23	17
2046	0.055	15	0.9	0.015	0.14	0.23	16
2047	0.054	15	0.9	0.015	0.15	0.24	16
2048	0.053	15	0.91	0.015	0.15	0.24	16
2049	0.053	15	0.9	0.015	0.15	0.25	16
2050	0.052	15	0.9	0.015	0.16	0.25	16
PV, 3%	$1.3	$280	$9.6	$0.16	$4.9	$8.1	$300
PV, 7%	$0.84	$160	$4.8	$0.08	$3.2	$5.3	$180
Annualized, 3%	$0.069	$14	$0.49	$0.0082	$0.25	$0.42	$15
Annualized, 7%	$0.068	$13	$0.39	$0.0065	$0.26	$0.43	$14

Notes:
"Foregone Consumer Sales Surplus" refers to the difference between a vehicle's price and the buyer's willingness to pay for the new vehicle; the impact reflects the reduction in new vehicle sales described in Chapter 8.1.

6.1.2 Alternatives

Table 6-2: Costs Associated with the Proposal Relative to the No Action Scenario ($Billions of 2018 dollars)

Calendar Year	Foregone Consumer Sales Surplus	Technology Costs	Congestion	Noise	Fatality Costs	Non-fatal Crash Costs	Total Costs
2023	0.025	4.7	0.014	0.00021	0.11	0.18	5
2024	0.032	6.5	0.026	0.0004	0.19	0.32	7.1
2025	0.06	9.9	0.052	0.00083	0.25	0.42	11
2026	0.061	10	0.086	0.0014	0.32	0.54	11
2027	0.066	12	0.14	0.0022	0.34	0.56	13
2028	0.062	12	0.19	0.0031	0.34	0.56	13
2029	0.051	11	0.24	0.0039	0.32	0.53	12
2030	0.046	11	0.3	0.0049	0.28	0.46	12
2031	0.046	11	0.34	0.0056	0.26	0.42	12
2032	0.043	11	0.39	0.0064	0.23	0.38	12
2033	0.042	11	0.43	0.007	0.21	0.34	12
2034	0.04	11	0.47	0.0077	0.18	0.3	12
2035	0.038	11	0.5	0.0082	0.16	0.27	12
2036	0.037	10	0.53	0.0087	0.14	0.23	11
2037	0.035	10	0.56	0.0091	0.12	0.2	11
2038	0.033	9.8	0.58	0.0094	0.11	0.18	11
2039	0.032	9.7	0.59	0.0096	0.097	0.16	11
2040	0.031	9.7	0.61	0.0099	0.089	0.14	11
2041	0.03	9.6	0.62	0.01	0.082	0.13	11
2042	0.029	9.6	0.62	0.01	0.078	0.13	10
2043	0.029	9.7	0.63	0.01	0.075	0.12	11
2044	0.028	9.6	0.64	0.01	0.071	0.12	10
2045	0.028	9.4	0.64	0.01	0.071	0.12	10
2046	0.027	9.3	0.64	0.011	0.072	0.12	10
2047	0.027	9.2	0.65	0.011	0.072	0.12	10
2048	0.026	9.1	0.65	0.011	0.072	0.12	10
2049	0.026	9.1	0.65	0.011	0.072	0.12	10
2050	0.025	9.1	0.65	0.011	0.072	0.12	9.9
PV, 3%	$0.72	$170	$7	$0.11	$3.2	$5.3	$190
PV, 7%	$0.46	$100	$3.5	$0.057	$2.1	$3.5	$110
Annualized, 3%	$0.037	$8.9	$0.35	$0.0058	$0.16	$0.27	$9.8
Annualized, 7%	$0.037	$8.4	$0.28	$0.0046	$0.17	$0.29	$9.2
Notes: "Foregone Consumer Sales Surplus" refers to the difference between a vehicle's price and the buyer's willingness to pay for the new vehicle; the impact reflects the reduction in new vehicle sales described in Chapter 8.1.							

Table 6-3: Costs Associated with Alternative 2 minus 10 Relative to the No Action Scenario ($Billions of 2018 dollars)

Calendar Year	Foregone Consumer Sales Surplus	Technology Costs	Congestion	Noise	Fatality Costs	Non-fatal Crash Costs	Total Costs
2023	$0.06	$10	$0.051	$0.0008	$0.24	$0.4	$11
2024	$0.073	$12	$0.085	$0.0013	$0.38	$0.64	$14
2025	$0.091	$14	$0.13	$0.0021	$0.45	$0.75	$15
2026	$0.12	$17	$0.18	$0.0029	$0.5	$0.83	$19
2027	$0.13	$18	$0.25	$0.004	$0.55	$0.91	$20
2028	$0.13	$19	$0.32	$0.0053	$0.55	$0.91	$21
2029	$0.11	$18	$0.38	$0.0064	$0.52	$0.87	$20
2030	$0.096	$18	$0.45	$0.0076	$0.46	$0.75	$19
2031	$0.096	$18	$0.51	$0.0086	$0.41	$0.68	$19
2032	$0.091	$18	$0.57	$0.0096	$0.37	$0.61	$19
2033	$0.089	$18	$0.63	$0.01	$0.33	$0.54	$19
2034	$0.085	$18	$0.68	$0.011	$0.29	$0.47	$19
2035	$0.081	$17	$0.72	$0.012	$0.25	$0.41	$19
2036	$0.077	$17	$0.76	$0.013	$0.22	$0.35	$19
2037	$0.074	$17	$0.79	$0.013	$0.19	$0.31	$18
2038	$0.07	$16	$0.82	$0.014	$0.16	$0.27	$18
2039	$0.068	$16	$0.84	$0.014	$0.15	$0.24	$18
2040	$0.066	$16	$0.86	$0.014	$0.13	$0.22	$17
2041	$0.064	$16	$0.88	$0.015	$0.12	$0.2	$17
2042	$0.062	$16	$0.89	$0.015	$0.12	$0.19	$17
2043	$0.061	$16	$0.9	$0.015	$0.11	$0.18	$17
2044	$0.06	$16	$0.9	$0.015	$0.11	$0.18	$17
2045	$0.06	$16	$0.9	$0.015	$0.11	$0.18	$17
2046	$0.058	$15	$0.91	$0.015	$0.12	$0.19	$17
2047	$0.056	$15	$0.91	$0.015	$0.12	$0.19	$17
2048	$0.055	$15	$0.91	$0.015	$0.12	$0.2	$16
2049	$0.055	$15	$0.9	$0.015	$0.12	$0.2	$16
2050	$0.054	$15	$0.9	$0.015	$0.13	$0.21	$16
PV, 3%	$1.5	$290	$10	$0.17	$5.3	$8.7	$320
PV, 7%	$0.94	$180	$5.2	$0.088	$3.6	$5.9	$190
Annualized, 3%	$0.075	$15	$0.52	$0.0087	$0.27	$0.44	$16
Annualized, 7%	$0.076	$14	$0.42	$0.0071	$0.29	$0.48	$15

Notes:
"Foregone Consumer Sales Surplus" refers to the difference between a vehicle's price and the buyer's willingness to pay for the new vehicle; the impact reflects the reduction in new vehicle sales described in Chapter 8.1.

6.2 Fuel Savings

Fuel savings presented here include fuel expenditure impacts for all fuels, including increased expenditures on electricity and include rebound effects, credit usage and advanced technology multiplier use. The net benefits calculations use the aggregate value of fuel savings (calculated using pre-tax fuel prices) since savings in fuel taxes do not represent a reduction in the value of economic resources utilized in producing and consuming fuel.

6.2.1 Final Rule

Table 6-4: Fuel Savings Associated with the Final Program ($Billions of 2018 dollars)

Calendar Year	Retail Fuel Savings	Fuel Tax Savings	Pre-Tax Fuel Savings
2023	$0.94	$0.31	$0.62
2024	$1.9	$0.64	$1.2
2025	$3.2	$1.1	$2.1
2026	$5.1	$1.7	$3.3
2027	$7.4	$2.4	$4.9
2028	$10	$3.2	$6.9
2029	$13	$3.8	$8.8
2030	$16	$4.5	$12
2031	$18	$5.1	$13
2032	$21	$5.6	$16
2033	$24	$6.2	$17
2034	$26	$6.7	$19
2035	$28	$7.1	$21
2036	$30	$7.5	$23
2037	$32	$7.8	$24
2038	$34	$8.1	$26
2039	$35	$8.3	$27
2040	$37	$8.5	$29
2041	$38	$8.6	$30
2042	$39	$8.7	$31
2043	$40	$8.8	$31
2044	$41	$8.8	$32
2045	$41	$8.8	$32
2046	$42	$8.8	$33
2047	$42	$8.8	$33
2048	$42	$8.7	$33
2049	$42	$8.7	$33
2050	$42	$8.6	$33
PV, 3%	$420	$100	$320
PV, 7%	$210	$51	$150
Annualized, 3%	$21	$5.1	$16
Annualized, 7%	$17	$4.1	$12

6.2.2 Alternatives

Table 6-5: Fuel Savings Associated with the Proposal ($Billions of 2018 dollars)

Calendar Year	Retail Fuel Savings	Fuel Tax Savings	Pre-Tax Fuel Savings
2023	$0.62	$0.23	$0.39
2024	$1.3	$0.47	$0.78
2025	$2.3	$0.84	$1.5
2026	$3.5	$1.2	$2.3
2027	$5.1	$1.7	$3.4
2028	$6.8	$2.2	$4.7
2029	$8.5	$2.6	$6
2030	$11	$3	$7.7
2031	$12	$3.4	$8.9
2032	$14	$3.7	$10
2033	$16	$4	$11
2034	$17	$4.4	$13
2035	$18	$4.6	$14
2036	$20	$4.9	$15
2037	$21	$5	$16
2038	$22	$5.2	$17
2039	$23	$5.3	$18
2040	$24	$5.4	$18
2041	$25	$5.5	$19
2042	$25	$5.5	$20
2043	$26	$5.6	$20
2044	$26	$5.6	$21
2045	$26	$5.6	$20
2046	$27	$5.6	$21
2047	$27	$5.6	$21
2048	$27	$5.6	$21
2049	$27	$5.6	$21
2050	$27	$5.5	$22
PV, 3%	$270	$65	$210
PV, 7%	$130	$33	$100
Annualized, 3%	$14	$3.3	$11
Annualized, 7%	$11	$2.7	$8.2

Table 6-6: Fuel Savings Associated with Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Retail Fuel Savings	Fuel Tax Savings	Pre-Tax Fuel Savings
2023	$1.4	$0.47	$0.94
2024	$2.6	$0.88	$1.7
2025	$4.1	$1.4	$2.7
2026	$6	$2	$4
2027	$8.3	$2.7	$5.6
2028	$11	$3.4	$7.6
2029	$14	$4.1	$9.5
2030	$17	$4.7	$12
2031	$19	$5.3	$14
2032	$22	$5.9	$16
2033	$24	$6.4	$18
2034	$27	$6.8	$20
2035	$29	$7.3	$21
2036	$31	$7.6	$23
2037	$33	$7.9	$25
2038	$34	$8.2	$26
2039	$36	$8.4	$27
2040	$37	$8.5	$29
2041	$38	$8.6	$30
2042	$39	$8.7	$31
2043	$40	$8.8	$31
2044	$41	$8.8	$32
2045	$40	$8.8	$32
2046	$41	$8.8	$33
2047	$42	$8.8	$33
2048	$42	$8.8	$33
2049	$42	$8.7	$33
2050	$42	$8.7	$33
PV, 3%	$430	$100	$320
PV, 7%	$210	$53	$160
Annualized, 3%	$22	$5.2	$16
Annualized, 7%	$17	$4.2	$13

6.3 Non-Emission Benefits

Non-emission benefits include the drive value, or drive surplus (see Chapter 3.4) and the energy security benefits (see Chapter 3.2). With changes in fuel consumption, there are also associated changes in the amount of time spent refueling vehicles. Consistent with the assumptions used in the NPRM (and presented in Table 6-7 and Table 6-8), the costs of time spent refueling are calculated as the total amount of time the driver of a typical vehicle would spend refueling multiplied by the value of their time. If less time is spent refueling vehicles under the revised standards, then a refueling time savings would be incurred and vice versa.

Table 6-7: CCEMS Inputs used to Estimate Refueling Time Costs

	Cars	Vans/SUVs	Pickups
Fixed Component of Average Refueling Time in Minutes (by Fuel Type)			
Gasoline	3.5	3.5	3.5
Ethanol-85	3.5	3.5	3.5
Diesel	3.5	3.5	3.5
Electricity	3.5	3.5	3.5
Hydrogen	0	0	0
Compressed Natural Gas	0	0	0
Average Tank Volume Refueled	65%	65%	65%
Value of Travel Time per Vehicle (2018 $/hour)	20.46	20.79	20.79

Table 6-8: CCEMS Inputs used to Estimate Electric Refueling Time Costs

	Cars	Vans/SUVs	Pickups
Electric Vehicle Recharge Thresholds (BEV200)			
Miles until mid-trip charging event	2,000	1,500	1,600
Share of miles charged mid-trip	6.00%	9.00%	8.00%
Charge rate (miles/hour)	67	67	67
Electric Vehicle Recharge Thresholds (BEV300)			
Miles until mid-trip charging event	5,200	3,500	3,800
Share of miles charged mid-trip	3.00%	4.00%	4.00%
Charge rate (miles/hour)	100	100	100

6.3.1 Non-emission Benefits of the Final Rule

Table 6-9: Benefits from Non-Emission Sources under the Final Rule ($Billions of 2018 dollars)

Calendar Year	Drive Value	Refueling Time Savings	Energy Security Benefits	Total Non-Emission Benefits
2023	$0.035	-$0.0052	$0.031	$0.061
2024	$0.055	-$0.03	$0.065	$0.09
2025	$0.091	-$0.07	$0.11	$0.13
2026	$0.14	-$0.12	$0.18	$0.2
2027	$0.22	-$0.15	$0.26	$0.33
2028	$0.32	-$0.19	$0.34	$0.47
2029	$0.42	-$0.23	$0.43	$0.61
2030	$0.55	-$0.27	$0.51	$0.79
2031	$0.64	-$0.29	$0.59	$0.94
2032	$0.74	-$0.34	$0.68	$1.1
2033	$0.83	-$0.38	$0.76	$1.2
2034	$0.93	-$0.43	$0.84	$1.3
2035	$1	-$0.47	$0.92	$1.5
2036	$1.1	-$0.51	$0.99	$1.6
2037	$1.2	-$0.56	$1.1	$1.7
2038	$1.2	-$0.6	$1.1	$1.8
2039	$1.3	-$0.63	$1.2	$1.8
2040	$1.3	-$0.67	$1.3	$1.9
2041	$1.4	-$0.69	$1.3	$2
2042	$1.4	-$0.7	$1.3	$2
2043	$1.4	-$0.72	$1.4	$2.1
2044	$1.4	-$0.73	$1.4	$2.1
2045	$1.4	-$0.75	$1.5	$2.1
2046	$1.5	-$0.77	$1.5	$2.2
2047	$1.5	-$0.78	$1.5	$2.2
2048	$1.5	-$0.81	$1.5	$2.2
2049	$1.5	-$0.82	$1.6	$2.2
2050	$1.5	-$0.83	$1.6	$2.3
PV, 3%	$15	$-7.4	$14	$21
PV, 7%	$7.2	$-3.6	$7	$11
Annualized, 3%	$0.75	$-0.38	$0.73	$1.1
Annualized, 7%	$0.58	$-0.29	$0.56	$0.85

6.3.2 Non-emission Benefits of the Proposal and Alternative

Table 6-10: Benefits from Non-Emission Sources Under the Proposal ($Billions of 2018 dollars)

Calendar Year	Drive Value	Refueling Time Savings	Energy Security Benefits	Total Non-Emission Benefits
2023	$0.013	-$0.019	$0.023	$0.017
2024	$0.021	-$0.05	$0.048	$0.019
2025	$0.045	-$0.091	$0.086	$0.04
2026	$0.085	-$0.12	$0.13	$0.094
2027	$0.15	-$0.14	$0.18	$0.19
2028	$0.22	-$0.16	$0.24	$0.29
2029	$0.29	-$0.18	$0.29	$0.4
2030	$0.38	-$0.19	$0.34	$0.54
2031	$0.45	-$0.19	$0.39	$0.66
2032	$0.53	-$0.21	$0.45	$0.77
2033	$0.59	-$0.24	$0.5	$0.85
2034	$0.66	-$0.26	$0.55	$0.95
2035	$0.72	-$0.29	$0.6	$1
2036	$0.77	-$0.31	$0.65	$1.1
2037	$0.82	-$0.32	$0.69	$1.2
2038	$0.86	-$0.32	$0.73	$1.3
2039	$0.88	-$0.33	$0.77	$1.3
2040	$0.93	-$0.34	$0.81	$1.4
2041	$0.95	-$0.35	$0.83	$1.4
2042	$0.97	-$0.34	$0.86	$1.5
2043	$0.99	-$0.36	$0.88	$1.5
2044	$1	-$0.38	$0.91	$1.5
2045	$0.99	-$0.39	$0.92	$1.5
2046	$1	-$0.41	$0.95	$1.6
2047	$1	-$0.42	$0.97	$1.6
2048	$1	-$0.44	$0.99	$1.6
2049	$1	-$0.47	$1	$1.6
2050	$1	-$0.49	$1	$1.6
PV, 3%	$10	$-4.4	$9.3	$15
PV, 7%	$5	$-2.3	$4.6	$7.3
Annualized, 3%	$0.52	$-0.22	$0.47	$0.77
Annualized, 7%	$0.4	$-0.18	$0.37	$0.59

Table 6-11: Benefits from Non-Emission Sources under Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Drive Value	Refueling Time Savings	Energy Security Benefits	Total Non-Emission Benefits
2023	$0.06	-$0.015	$0.047	$0.092
2024	$0.099	-$0.036	$0.089	$0.15
2025	$0.15	-$0.057	$0.14	$0.24
2026	$0.22	-$0.094	$0.21	$0.33
2027	$0.3	-$0.13	$0.28	$0.46
2028	$0.41	-$0.18	$0.37	$0.6
2029	$0.5	-$0.22	$0.45	$0.74
2030	$0.63	-$0.27	$0.54	$0.9
2031	$0.72	-$0.31	$0.62	$1
2032	$0.83	-$0.35	$0.7	$1.2
2033	$0.92	-$0.39	$0.78	$1.3
2034	$1	-$0.42	$0.86	$1.5
2035	$1.1	-$0.45	$0.94	$1.6
2036	$1.2	-$0.49	$1	$1.7
2037	$1.2	-$0.51	$1.1	$1.8
2038	$1.3	-$0.52	$1.2	$1.9
2039	$1.3	-$0.54	$1.2	$2
2040	$1.4	-$0.55	$1.3	$2.1
2041	$1.4	-$0.55	$1.3	$2.2
2042	$1.5	-$0.57	$1.4	$2.2
2043	$1.5	-$0.59	$1.4	$2.3
2044	$1.5	-$0.61	$1.4	$2.3
2045	$1.5	-$0.62	$1.5	$2.3
2046	$1.5	-$0.64	$1.5	$2.4
2047	$1.5	-$0.69	$1.5	$2.4
2048	$1.5	-$0.76	$1.6	$2.3
2049	$1.5	-$0.81	$1.6	$2.3
2050	$1.5	-$0.86	$1.6	$2.3
PV, 3%	$16	$-6.7	$15	$24
PV, 7%	$7.9	$-3.3	$7.2	$12
Annualized, 3%	$0.81	$-0.34	$0.75	$1.2
Annualized, 7%	$0.64	$-0.27	$0.58	$0.95

Chapter 7: Non-GHG Health and Environmental Impacts

In this chapter we discuss the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants will not be directly regulated by the standards, but the standards will affect emissions of these pollutants and precursors.

7.1 Health and Environmental Impacts of Non-GHG Pollutants

7.1.1 Background on Non-GHG Pollutants Impacted by the Final Standards

7.1.1.1 Particulate Matter

Particulate matter (PM) is a complex mixture of solid particles and liquid droplets distributed among numerous atmospheric gases which interact with solid and liquid phases. Particles in the atmosphere range in size from less than 0.01 to more than 10 micrometers (μm) in diameter.[1] Atmospheric particles can be grouped into several classes according to their aerodynamic diameter and physical sizes. Generally, the three broad classes of particles include ultrafine particles (UFPs, generally considered as particles with a diameter less than or equal to 0.1 μm [typically based on physical size, thermal diffusivity or electrical mobility]), “fine” particles ($PM_{2.5}$; particles with a nominal mean aerodynamic diameter less than or equal to 2.5 μm), and “thoracic” particles (PM_{10}; particles with a nominal mean aerodynamic diameter less than or equal to 10 μm). Particles that fall within the size range between $PM_{2.5}$ and PM_{10}, are referred to as “thoracic coarse particles” ($PM_{10-2.5}$, particles with a nominal mean aerodynamic diameter greater than 2.5 μm and less than or equal to 10 μm). EPA currently has NAAQS for $PM_{2.5}$ and PM_{10}.[a]

Most particles are found in the lower troposphere, where they can have residence times ranging from a few hours to weeks. Particles are removed from the atmosphere by wet deposition, such as when they are carried by rain or snow, or by dry deposition, when particles settle out of suspension due to gravity. Atmospheric lifetimes are generally longest for $PM_{2.5}$, which often remains in the atmosphere for days to weeks before being removed by wet or dry deposition.[2] In contrast, atmospheric lifetimes for UFP and $PM_{10–2.5}$ are shorter. Within hours, UFP can undergo coagulation and condensation that lead to formation of larger particles in the accumulation mode, or can be removed from the atmosphere by evaporation, deposition, or reactions with other atmospheric components. $PM_{10–2.5}$ are also generally removed from the atmosphere within hours, through wet or dry deposition.[3]

Particulate matter consists of both primary and secondary particles. Primary particles are emitted directly from sources, such as combustion-related activities (e.g., industrial activities, motor vehicle operation, biomass burning), while secondary particles are formed through atmospheric chemical reactions of gaseous precursors (e.g., sulfur oxides (SO_X), nitrogen oxides (NO_X) and volatile organic compounds (VOCs)). From 2000 to 2017, national annual average

[a] Regulatory definitions of PM size fractions, and information on reference and equivalent methods for measuring PM in ambient air, are provided in 40 CFR Parts 50, 53, and 58. With regard to national ambient air quality standards (NAAQS) which provide protection against health and welfare effects, the 24-hour PM10 standard provides protection against effects associated with short-term exposure to thoracic coarse particles (i.e., PM10-2.5).

ambient $PM_{2.5}$ concentrations have declined by over 40 percent,[4] largely reflecting reductions in emissions of precursor gases.

7.1.1.2 Ozone

Ground-level ozone pollution forms in areas with high concentrations of ambient NO_X and VOCs when solar radiation is strong. Major U.S. sources of NO_X are highway and nonroad motor vehicles, engines, power plants and other industrial sources, with natural sources, such as soil, vegetation, and lightning, serving as smaller sources. Vegetation is the dominant source of VOCs in the U.S. Volatile consumer and commercial products, such as propellants and solvents, highway and nonroad vehicles, engines, fires, and industrial sources also contribute to the atmospheric burden of VOCs at ground-level.

The processes underlying ozone formation, transport, and accumulation are complex. Ground-level ozone is produced and destroyed by an interwoven network of free radical reactions involving the hydroxyl radical (OH), NO, NO_2, and complex reaction intermediates derived from VOCs. Many of these reactions are sensitive to temperature and available sunlight. High ozone events most often occur when ambient temperatures and sunlight intensities remain high for several days under stagnant conditions. Ozone and its precursors can also be transported hundreds of miles downwind which can lead to elevated ozone levels in areas with otherwise low VOC or NO_X emissions. As an air mass moves and is exposed to changing ambient concentrations of NO_X and VOCs, the ozone photochemical regime (relative sensitivity of ozone formation to NO_X and VOC emissions) can change.

When ambient VOC concentrations are high, comparatively small amounts of NO_X catalyze rapid ozone formation. Without available NO_X, ground-level ozone production is severely limited and VOC reductions will have little impact on ozone concentrations. Photochemistry under these conditions is said to be "NO_X-limited." When NO_X levels are sufficiently high, faster NO_2 oxidation consumes more radicals, dampening ozone production. Under these "VOC-limited" conditions (also referred to as "NO_X-saturated" conditions), VOC reductions are effective in reducing ozone, and NO_X can react directly with ozone resulting in suppressed ozone concentrations near NO_X emission sources. Under these NO_X-saturated conditions, NO_X reductions can actually increase local ozone under certain circumstances, but overall ozone production (considering downwind formation) decreases and even in VOC-limited areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large - large enough to become NO_X-limited.

7.1.1.3 Nitrogen Oxides

Oxides of nitrogen (NO_X) refers to nitric oxide (NO) and nitrogen dioxide (NO_2). Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. NO_X is a criteria pollutant, regulated for its adverse effects on public health and the environment, and highway vehicles are an important contributor to NO_X emissions. NO_X, along with VOCs, are the two major precursors of ozone and NO_X is also a major contributor to secondary $PM_{2.5}$ formation.

7.1.1.4 Sulfur Oxides

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (e.g., coal or oil), extracting gasoline from oil, or extracting metals from ore. SO_2 and its gas phase oxidation products can dissolve in water droplets and further oxidize to form sulfuric acid which reacts with ammonia to form sulfates, which are important components of ambient PM.

7.1.1.5 Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources.[5]

7.1.1.6 Air Toxics

Light-duty engine emissions contribute to ambient levels of air toxics that are known or suspected human or animal carcinogens, or that have noncancer health effects. These compounds include, but are not limited to, benzene, formaldehyde, acetaldehyde, naphthalene, and 1,3-butadiene. These compounds were identified as national or regional risk drivers or contributors in the 2014 National-scale Air Toxics Assessment and have significant inventory contributions from mobile sources.[6,7]

7.1.2 Health Effects Associated with Exposure to Non-GHG Pollutants

7.1.2.1 Particulate Matter

Scientific evidence spanning animal toxicological, controlled human exposure, and epidemiologic studies shows that exposure to ambient PM is associated with a broad range of health effects. These health effects are discussed in detail in the Integrated Science Assessment for Particulate Matter (PM ISA), which was finalized in December 2019.[8] The PM ISA characterizes the causal nature of relationships between PM exposure and broad health categories (e.g., cardiovascular effects, respiratory effects, etc.) using a weight-of-evidence approach.[b,9] Within this characterization, the PM ISA summarizes the health effects evidence for short- and long-term exposures to $PM_{2.5}$, $PM_{10-2.5}$, and ultrafine particles, and concludes that human exposures to ambient $PM_{2.5}$ are associated with a number of adverse health effects. The discussion below highlights the PM ISA's conclusions pertaining to the health effects evidence for both short- and long-term PM exposures. Further discussion of PM-related health effects can also be found in the 2020 Policy Assessment for the review of the PM NAAQS.[10]

EPA has concluded that recent evidence in combination with evidence evaluated in the 2009 PM ISA supports a "causal relationship" between both long- and short-term exposures to $PM_{2.5}$ and premature mortality and cardiovascular effects and a "likely to be causal relationship" between long- and short-term $PM_{2.5}$ exposures and respiratory effects.[11] Additionally, recent experimental and epidemiologic studies provide evidence supporting a "likely to be causal

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[b] The causal framework draws upon the assessment and integration of evidence from across scientific disciplines, spanning atmospheric chemistry, exposure, dosimetry and health effects studies (i.e., epidemiologic, controlled human exposure, and animal toxicological studies), and assess the related uncertainties and limitations that ultimately influence our understanding of the evidence. This framework employs a five-level hierarchy that classifies the overall weight-of-evidence with respect to the causal nature of relationships between criteria pollutant exposures and health and welfare effects using the following categorizations: causal relationship; likely to be causal relationship; suggestive of, but not sufficient to infer, a causal relationship; inadequate to infer the presence or absence of a causal relationship; and not likely to be a causal relationship.

relationship" between long-term $PM_{2.5}$ exposure and nervous system effects, and long-term $PM_{2.5}$ exposure and cancer. In contrast, EPA determined that the more limited and uncertain evidence was "suggestive of, but not sufficient to infer, a causal relationship" for long-term $PM_{2.5}$ exposure and reproductive and developmental effects (i.e., male/female reproduction and fertility; pregnancy and birth outcomes), long- and short-term exposures and metabolic effects, and short-term exposure and nervous system effects.

As discussed extensively in the 2019 PM ISA, recent studies continue to support and extend the evidence base linking short- and long-term $PM_{2.5}$ exposures and mortality.[8] For short-term $PM_{2.5}$ exposure, recent multi-city studies, in combination with single- and multi-city studies evaluated in the 2009 PM ISA, provide evidence of consistent, positive associations across studies conducted in different geographic locations, populations with different demographic characteristics, and studies using different exposure assignment techniques. Additionally, the consistent and coherent evidence across scientific disciplines for cardiovascular morbidity, particularly ischemic events and heart failure, and to a lesser degree for respiratory morbidity, with the strongest evidence for exacerbations of chronic obstructive pulmonary disease (COPD) and asthma, provide biological plausibility for cause-specific mortality and ultimately total mortality.

In addition to re-analyses and extensions of the American Cancer Society (ACS) and Harvard Six Cities (HSC) cohorts, multiple new cohort studies conducted in the U.S. and Canada consisting of people employed in a specific job (e.g., teacher, nurse), and that apply different exposure assignment techniques provide evidence of positive associations between long-term $PM_{2.5}$ exposure and mortality. Biological plausibility for mortality due to long-term $PM_{2.5}$ exposure is provided by the coherence of effects across scientific disciplines for cardiovascular morbidity, particularly for coronary heart disease (CHD), stroke and atherosclerosis, and for respiratory morbidity, particularly for the development of COPD. Additionally, recent studies provide evidence indicating that as long-term $PM_{2.5}$ concentrations decrease there is an increase in life expectancy.

A large body of recent studies examining both short- and long-term $PM_{2.5}$ exposure and cardiovascular effects supports and extends the evidence base evaluated in the 2009 PM ISA. Some of the strongest evidence from both experimental and epidemiologic studies examining short-term $PM_{2.5}$ exposures are for ischemic heart disease (IHD) and heart failure. The evidence for cardiovascular effects is coherent across studies of short-term $PM_{2.5}$ exposure that have observed associations with a continuum of effects ranging from subtle changes in indicators of cardiovascular health to serious clinical events, such as increased emergency department visits and hospital admissions due to cardiovascular disease and cardiovascular mortality. For long-term $PM_{2.5}$ exposure, there is strong and consistent epidemiologic evidence of a relationship with cardiovascular mortality. This evidence is supported by epidemiologic and animal toxicological studies demonstrating a range of cardiovascular effects including coronary heart disease, stroke, impaired heart function, and subclinical markers (e.g., coronary artery calcification, atherosclerotic plaque progression), which collectively provide coherence and biological plausibility.

Recent studies continue to provide evidence of a relationship between both short- and long-term $PM_{2.5}$ exposure and respiratory effects. Epidemiologic and animal toxicological studies examining short-term $PM_{2.5}$ exposure provide consistent evidence of asthma and COPD exacerbations, in children and adults, respectively. This evidence is supported by epidemiologic studies examining asthma and COPD emergency department visits and hospital admissions, as well as, respiratory mortality. However, there is inconsistent evidence of respiratory effects, specifically lung function declines and pulmonary inflammation, in controlled human exposure studies. Epidemiologic studies conducted in the U.S. and abroad provide evidence of a relationship between long-term $PM_{2.5}$ exposure and respiratory effects, including consistent changes in lung function and lung function growth rate, increased asthma incidence, asthma prevalence, and wheeze in children; acceleration of lung function decline in adults; and respiratory mortality. The epidemiologic evidence is supported by animal toxicological studies, which provide coherence and biological plausibility for a range of effects including impaired lung development, decrements in lung function growth, and asthma development.

Since the 2009 PM ISA, a growing body of scientific evidence examined the relationship between long-term $PM_{2.5}$ exposure and nervous system effects, resulting for the first time in a causality determination for this health effects category. The strongest evidence for effects on the nervous system come from epidemiologic studies that consistently report cognitive decrements and reductions in brain volume in adults. The effects observed in epidemiologic studies are supported by animal toxicological studies demonstrating effects on the brain of adult animals including inflammation, morphologic changes, and neurodegeneration of specific regions of the brain. There is more limited evidence for neurodevelopmental effects in children with some studies reporting positive associations with autism spectrum disorder (ASD) and others providing limited evidence of an association with cognitive function. While there is some evidence from animal toxicological studies indicating effects on the brain (i.e., inflammatory and morphological changes) to support a biologically plausible pathway, epidemiologic studies of neurodevelopmental effects are limited due to their lack of control for potential confounding by copollutants, the small number of studies conducted, and uncertainty regarding critical exposure windows.

Building off the decades of research demonstrating mutagenicity, DNA damage, and endpoints related to genotoxicity due to whole PM exposures, recent experimental and epidemiologic studies focusing specifically on $PM_{2.5}$ provide evidence of a relationship between long-term $PM_{2.5}$ exposure and cancer. Epidemiologic studies examining long-term $PM_{2.5}$ exposure and lung cancer incidence and mortality provide evidence of generally positive associations in cohort studies spanning different populations, locations, and exposure assignment techniques. Additionally, there is evidence of positive associations in analyses limited to never smokers. The epidemiologic evidence is supported by both experimental and epidemiologic evidence of genotoxicity, epigenetic effects, carcinogenic potential, and that $PM_{2.5}$ exhibits several characteristics of carcinogens, which collectively provides biological plausibility for cancer development.

For the additional health effects categories evaluated for $PM_{2.5}$ in the 2019 PM ISA, experimental and epidemiologic studies provide limited and/or inconsistent evidence of a relationship with $PM_{2.5}$ exposure. As a result, the 2019 PM ISA concluded that the evidence is "suggestive of, but not sufficient to infer a causal relationship" for short-term $PM_{2.5}$ exposure and metabolic effects and nervous system effects, and long-term $PM_{2.5}$ exposures and metabolic effects as well as reproductive and developmental effects.

In addition to evaluating the health effects attributed to short- and long-term exposure to $PM_{2.5}$, the 2019 PM ISA also conducted an extensive evaluation as to whether specific components or sources of $PM_{2.5}$ are more strongly related with health effects than $PM_{2.5}$ mass. An evaluation of those studies resulted in the 2019 PM ISA concluding that "many $PM_{2.5}$ components and sources are associated with many health effects, and the evidence does not indicate that any one source or component is consistently more strongly related to health effects than $PM_{2.5}$ mass."[8]

For both $PM_{10-2.5}$ and UFPs, for all health effects categories evaluated, the 2019 PM ISA concluded that the evidence was "suggestive of, but not sufficient to infer, a causal relationship" or "inadequate to determine the presence or absence of a causal relationship." For $PM_{10-2.5}$, although a Federal Reference Method (FRM) was instituted in 2011 to measure $PM_{10-2.5}$ concentrations nationally, the causality determinations reflect that the same uncertainty identified in the 2009 PM ISA with respect to the method used to estimate $PM_{10-2.5}$ concentrations in epidemiologic studies persists. Specifically, across epidemiologic studies, different approaches are used to estimate $PM_{10-2.5}$ concentrations (e.g., direct measurement of $PM_{10-2.5}$, difference between PM_{10} and $PM_{2.5}$ concentrations), and it remains unclear how well correlated $PM_{10-2.5}$ concentrations are both spatially and temporally across the different methods used.

For UFPs, the uncertainty in the evidence for the health effect categories evaluated across experimental and epidemiologic studies reflects the inconsistency in the exposure metric used (i.e., particle number concentration, surface area concentration, mass concentration) as well as the size fractions examined. In epidemiologic studies the size fraction can vary depending on the monitor used and exposure metric, with some studies examining number count over the entire particle size range, while experimental studies that use a particle concentrator often examine particles up to 0.3 µm. Additionally, due to the lack of a monitoring network, there is limited information on the spatial and temporal variability of UFPs within the U.S., as well as population exposures to UFPs, which adds uncertainty to epidemiologic study results.

The 2019 PM ISA cites extensive evidence indicating that "both the general population as well as specific populations and lifestages are at risk for $PM_{2.5}$-related health effects."[8,10] For example, in support of its "causal" and "likely to be causal" determinations, the ISA cites substantial evidence for (1) PM-related mortality and cardiovascular effects in older adults; (2) PM-related cardiovascular effects in people with pre-existing cardiovascular disease; (3) PM-related respiratory effects in people with pre-existing respiratory disease, particularly asthma exacerbations in children; and (4) PM-related impairments in lung function growth and asthma development in children. The ISA additionally notes that stratified analyses (i.e., analyses that directly compare PM-related health effects across groups) provide strong evidence for racial and ethnic differences in $PM_{2.5}$ exposures and in the risk of $PM_{2.5}$-related health effects, specifically within Hispanic and non-Hispanic black populations. Additionally, evidence spanning epidemiologic studies that conducted stratified analyses, experimental studies focusing on animal models of disease or individuals with pre-existing disease, dosimetry studies, as well as studies focusing on differential exposure suggest that populations with pre-existing cardiovascular or respiratory disease, populations that are overweight or obese, populations that have particular genetic variants, populations that are of low socioeconomic status, and current/former smokers could be at increased risk for adverse $PM_{2.5}$-related health effects.

7.1.2.2 Ozone

This section provides a summary of the health effects associated with exposure to ambient concentrations of ozone.[12] The information in this section is based on the information and conclusions in the April 2020 Integrated Science Assessment for Ozone (Ozone ISA).[13] The Ozone ISA concludes that human exposures to ambient concentrations of ozone are associated with a number of adverse health effects and characterizes the weight of evidence for these health effects.[14] The discussion below highlights the Ozone ISA's conclusions pertaining to health effects associated with both short-term and long-term periods of exposure to ozone.

For short-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including lung function decrements, pulmonary inflammation, exacerbation of asthma, respiratory-related hospital admissions, and mortality, are causally associated with ozone exposure. It also concludes that metabolic effects, including metabolic syndrome (i.e., changes in insulin or glucose levels, cholesterol levels, obesity and blood pressure) and complications due to diabetes are likely to be causally associated with short-term exposure to ozone and that evidence is suggestive of a causal relationship between cardiovascular effects, central nervous system effects and total mortality and short-term exposure to ozone.

For long-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including new onset asthma, pulmonary inflammation and injury, are likely to be causally related with ozone exposure. The Ozone ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term ozone exposure and cardiovascular effects, metabolic effects, reproductive and developmental effects, central nervous system effects and total mortality. The evidence is inadequate to infer a causal relationship between chronic ozone exposure and increased risk of cancer.

This section provides a summary of the health effects associated with exposure to ambient concentrations of ozone.[c] The information in this section is based on the information and conclusions in the April 2020 Integrated Science Assessment for Ozone (Ozone ISA).[15] The Ozone ISA concludes that human exposures to ambient concentrations of ozone are associated with a number of adverse health effects and characterizes the weight of evidence for these health effects.[d] The discussion below highlights the Ozone ISA's conclusions pertaining to health effects associated with both short-term and long-term periods of exposure to ozone.

For short-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including lung function decrements, pulmonary inflammation, exacerbation of asthma, respiratory-related hospital admissions, and mortality, are causally associated with ozone exposure. It also concludes that metabolic effects, including metabolic syndrome (i.e., changes in insulin or glucose levels, cholesterol levels, obesity and blood pressure) and complications due to diabetes

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[c] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notably different ozone concentrations. Also, the amount of ozone delivered to the lung is influenced not only by the ambient concentrations but also by the breathing route and rate.

[d] The ISA evaluates evidence and draws conclusions on the causal relationship between relevant pollutant exposures and health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II in the Preamble of the ISA.

are likely to be causally associated with short-term exposure to ozone and that evidence is suggestive of a causal relationship between cardiovascular effects, central nervous system effects and total mortality and short-term exposure to ozone.

For long-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including new onset asthma, pulmonary inflammation and injury, are likely to be causally related with ozone exposure. The Ozone ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term ozone exposure and cardiovascular effects, metabolic effects, reproductive and developmental effects, central nervous system effects and total mortality. The evidence is inadequate to infer a causal relationship between chronic ozone exposure and increased risk of cancer.

Finally, interindividual variation in human responses to ozone exposure can result in some groups being at increased risk for detrimental effects in response to exposure. In addition, some groups are at increased risk of exposure due to their activities, such as outdoor workers and children. The Ozone ISA identified several groups that are at increased risk for ozone-related health effects. These groups are people with asthma, children and older adults, individuals with reduced intake of certain nutrients (i.e., Vitamins C and E), outdoor workers, and individuals having certain genetic variants related to oxidative metabolism or inflammation. Ozone exposure during childhood can have lasting effects through adulthood. Such effects include altered function of the respiratory and immune systems. Children absorb higher doses (normalized to lung surface area) of ambient ozone, compared to adults, due to their increased time spent outdoors, higher ventilation rates relative to body size, and a tendency to breathe a greater fraction of air through the mouth. Children also have a higher asthma prevalence compared to adults. Recent epidemiologic studies provide generally consistent evidence that long-term ozone exposure is associated with the development of asthma in children. Studies comparing age groups reported higher magnitude associations for short-term ozone exposure and respiratory hospital admissions and emergency room visits among children than for adults. Panel studies also provide support for experimental studies with consistent associations between short-term ozone exposure and lung function and pulmonary inflammation in healthy children.

7.1.2.3 Nitrogen Oxides

The most recent review of the health effects of oxides of nitrogen completed by EPA can be found in the 2016 Integrated Science Assessment for Oxides of Nitrogen - Health Criteria (Oxides of Nitrogen ISA).[16] The primary source of NO_2 is motor vehicle emissions, and ambient NO_2 concentrations tend to be highly correlated with other traffic-related pollutants. Thus, a key issue in characterizing the causality of NO_2-health effect relationships consists of evaluating the extent to which studies supported an effect of NO_2 that is independent of other traffic-related pollutants. EPA concluded that the findings for asthma exacerbation integrated from epidemiologic and controlled human exposure studies provided evidence that is sufficient to infer a causal relationship between respiratory effects and short-term NO_2 exposure. The strongest evidence supporting an independent effect of NO_2 exposure comes from controlled human exposure studies demonstrating increased airway responsiveness in individuals with asthma following ambient-relevant NO_2 exposures. The coherence of this evidence with epidemiologic findings for asthma hospital admissions and ED visits as well as lung function decrements and increased pulmonary inflammation in children with asthma describe a plausible pathway by which NO_2 exposure can cause an asthma exacerbation. The 2016 ISA for Oxides of

Nitrogen also concluded that there is likely to be a causal relationship between long-term NO_2 exposure and respiratory effects. This conclusion is based on new epidemiologic evidence for associations of NO_2 with asthma development in children combined with biological plausibility from experimental studies.

In evaluating a broader range of health effects, the 2016 ISA for Oxides of Nitrogen concluded that evidence is “suggestive of, but not sufficient to infer, a causal relationship” between short-term NO_2 exposure and cardiovascular effects and mortality and between long-term NO_2 exposure and cardiovascular effects and diabetes, birth outcomes, and cancer. In addition, the scientific evidence is inadequate (insufficient consistency of epidemiologic and toxicological evidence) to infer a causal relationship for long-term NO_2 exposure with fertility, reproduction, and pregnancy, as well as with postnatal development. A key uncertainty in understanding the relationship between these non-respiratory health effects and short- or long-term exposure to NO_2 is co-pollutant confounding, particularly by other roadway pollutants. The available evidence for non-respiratory health effects does not adequately address whether NO_2 has an independent effect or whether it primarily represents effects related to other or a mixture of traffic-related pollutants.

The 2016 ISA for Oxides of Nitrogen concluded that people with asthma, children, and older adults are at increased risk for NO_2-related health effects. In these groups and lifestages, NO_2 is consistently related to larger effects on outcomes related to asthma exacerbation, for which there is confidence in the relationship with NO_2 exposure.

7.1.2.4 Sulfur Oxides

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the 2017 Integrated Science Assessment for Sulfur Oxides – Health Criteria (SO_X ISA).[17] Following an extensive evaluation of health evidence from animal toxicological, controlled human exposure, and epidemiologic studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. People with asthma are more sensitive to the effects of SO_2, likely resulting from preexisting inflammation associated with this disease. In addition to those with asthma (both children and adults), there is suggestive evidence that all children and older adults may be at increased risk of SO_2-related health effects. In free-breathing laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5-10 min exposures at SO_2 concentrations $\geq$ 400 ppb in people with asthma engaged in moderate to heavy levels of exercise, with respiratory effects occurring at concentrations as low as 200 ppb in some individuals with asthma. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 200 and 1000 ppb, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of individuals with asthma adversely affected. Epidemiologic studies have reported positive associations between short-term ambient SO_2 concentrations and hospital admissions and emergency department visits for asthma and for all respiratory causes, particularly among children and older adults ($\geq$ 65 years). The studies provide supportive evidence for the causal relationship.

For long-term SO_2 exposure and respiratory effects, the EPA has concluded that the evidence is suggestive of a causal relationship. This conclusion is based on new epidemiologic evidence for positive associations between long-term SO_2 exposure and increases in asthma incidence among children, together with animal toxicological evidence that provides a pathophysiologic basis for the development of asthma. However, uncertainty remains regarding the influence of other pollutants on the observed associations with SO_2 because these epidemiologic studies have not examined the potential for co-pollutant confounding.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these observed mortality associations due to potential confounding by various co-pollutants. Therefore, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

7.1.2.5 Carbon Monoxide

Information on the health effects of carbon monoxide (CO) can be found in the January 2010 Integrated Science Assessment for Carbon Monoxide (CO ISA).[18] The CO ISA presents conclusions regarding the presence of causal relationships between CO exposure and categories of adverse health effects.[19] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO, along with the CO ISA conclusions.[20]

Controlled human exposure studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies observed associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The CO ISA concludes that a causal relationship is likely to exist between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report central nervous system and behavioral effects following low-level CO exposures, although the findings have not been consistent across all studies. The CO ISA concludes that the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of studies cited in the CO ISA have evaluated the role of CO exposure in birth outcomes such as preterm birth or cardiac birth defects. There is limited epidemiologic evidence of a CO-induced effect on preterm births and birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found perinatal CO exposure to affect birth weight, as well as other developmental outcomes. The CO ISA concludes that the evidence is suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of associations between short-term CO concentrations and respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions. A limited number of epidemiologic studies considered copollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50-100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The CO ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the CO ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term concentrations of CO and mortality. Epidemiologic evidence suggests an association exists between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in co-pollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The CO ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

7.1.2.6 Air Toxics

7.1.2.6.1 Health Effects Associated with Exposure to Benzene

EPA's Integrated Risk Information System (IRIS) database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[21,22,23] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. EPA's IRIS documentation for benzene also lists a range of 2.2 x 10-6 to 7.8 x 10-6 per $\mu g/m^3$ as the unit risk estimate (URE) for benzene.[24,25] The International Agency for Research on Cancer (IARC) has determined that benzene is a human carcinogen, and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[26,27]

A number of adverse noncancer health effects, including blood disorders such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[28,29] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[30,31] EPA's inhalation reference concentration (RfC) for benzene is 30 $\mu g/m^3$. The RfC is based on suppressed absolute lymphocyte counts seen in humans under occupational exposure conditions. In addition, studies sponsored by the Health Effects Institute (HEI) provide evidence that biochemical responses occur at lower levels of benzene exposure than previously known.[32,33,34,35] EPA's IRIS program has not yet evaluated these new data. EPA does not currently have an acute reference concentration for benzene. The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Level (MRL) for acute exposure to benzene is 29 $\mu g/m^3$ for 1-14 days exposure.[36,37]

7.1.2.6.2 *Health Effects Associated with Exposure to Formaldehyde*

In 1991, EPA concluded that formaldehyde is a Class B1 probable human carcinogen based on limited evidence in humans and sufficient evidence in animals.[38] An Inhalation URE for cancer and a Reference Dose for oral noncancer effects were developed by EPA and posted on the IRIS database. Since that time, the NTP and IARC have concluded that formaldehyde is a known human carcinogen.[39,40,41]

The conclusions by IARC and NTP reflect the results of epidemiologic research published since 1991 in combination with previous animal, human and mechanistic evidence. Research conducted by the National Cancer Institute reported an increased risk of nasopharyngeal cancer and specific lymphohematopoietic malignancies among workers exposed to formaldehyde.[42,43,44] A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of death due to leukemia among workers exposed to formaldehyde.[45] Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[46] Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid leukemia but not brain cancer.[47]

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999, supplemented in 2010, and by the World Health Organization. [48,49,50] These organizations reviewed the scientific literature concerning health effects linked to formaldehyde exposure to evaluate hazards and dose response relationships and defined exposure concentrations for minimal risk levels (MRLs). The health endpoints reviewed included sensory irritation of eyes and respiratory tract, reduced pulmonary function, nasal histopathology, and immune system effects. In addition, research on reproductive and developmental effects and neurological effects were discussed along with several studies that suggest that formaldehyde may increase the risk of asthma – particularly in the young.

In June 2010, EPA released a draft Toxicological Review of Formaldehyde – Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment.[51] That draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011.[52] EPA's draft assessment, which addresses NRC recommendations, was suspended in 2018.[53] The draft assessment was unsuspended in March 2021.

7.1.2.6.3 *Health Effects Associated with Exposure to Acetaldehyde*

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[54] The URE in IRIS for acetaldehyde is $2.2 \times 10\text{-}6$ per $\mu g/m^3$.[55] Acetaldehyde is reasonably anticipated to be a human carcinogen by the NTP in the 14th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[56,57]

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[58] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[59,60] Data from these studies were used by EPA to develop an inhalation reference concentration of 9 $\mu g/m^3$. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[61] Children, especially those with diagnosed asthma, may be more likely to show impaired pulmonary function and symptoms of asthma than are adults following exposure to acetaldehyde.[62]

7.1.2.6.4 Health Effects Associated with Exposure to Naphthalene

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion.

Acute (short-term) exposure of humans to naphthalene by inhalation, ingestion, or dermal contact is associated with hemolytic anemia and damage to the liver and the nervous system.[63] Chronic (long term) exposure of workers and rodents to naphthalene has been reported to cause cataracts and retinal damage.[64] EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[65] The draft reassessment completed external peer review.[66] Based on external peer review comments received, EPA was developing a revised draft assessment that considers all routes of exposure, as well as cancer and noncancer effects; this reassessment was suspended in 2018.[67] The external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The NTP listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[68] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[69]

Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[70] The current EPA IRIS assessment includes noncancer data on hyperplasia and metaplasia in nasal tissue that form the basis of the inhalation RfC of 3 $\mu g/m^3$.[71] The ATSDR MRL for acute exposure to naphthalene is 0.6 mg/kg/day.

7.1.2.6.5 Health Effects Associated with Exposure to 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[72,73] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[74,75,76, 77] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. The URE for 1,3-butadiene is 3 × 10-5 per $\mu g/m^3$.[78] 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[79] Based on this critical effect and the benchmark concentration methodology, an RfC for chronic health effects was calculated at 0.9 ppb (approximately 2 $\mu g/m^3$).

7.1.2.6.6 Health effects Associated with exposure to other air toxics

In addition to the compounds described above, other compounds found in gaseous hydrocarbon and PM emissions from engines will be affected by this rulemaking. Mobile source air toxic compounds that will potentially be affected include acrolein, ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[80]

7.1.2.7 Exposure and Health Effects Associated with Traffic

Locations in close proximity to major roadways generally have elevated concentrations of many air pollutants emitted from motor vehicles. Hundreds of such studies have been published in peer-reviewed journals, concluding that concentrations of CO, CO_2, NO, NO_2, benzene, aldehydes, particulate matter, black carbon, and many other compounds are elevated in ambient air within approximately 300-600 meters (about 1,000-2,000 feet) of major roadways. The highest concentrations of most pollutants emitted directly by motor vehicles are found at locations within 50 meters (about 165 feet) of the edge of a roadway's traffic lanes.

A large-scale review of air quality measurements in the vicinity of major roadways between 1978 and 2008 concluded that the pollutants with the steepest concentration gradients in vicinities of roadways were CO, ultrafine particles, metals, elemental carbon (EC), NO, NO_X, and several VOCs.[81] These pollutants showed a large reduction in concentrations within 100 meters downwind of the roadway. Pollutants that showed more gradual reductions with distance from roadways included benzene, NO_2, $PM_{2.5}$, and PM_{10}. In the review article, results varied based on the method of statistical analysis used to determine the gradient in concentration. More recent studies continue to show significant concentration gradients of traffic-related air pollution around major roads.[82,83,84,85,86; 87,88,89] There is evidence that EPA's regulations for vehicles have lowered the near-road concentrations and gradients.[90]

For pollutants with relatively high background concentrations relative to near-road concentrations, detecting concentration gradients can be difficult. For example, many aldehydes have high background concentrations as a result of photochemical breakdown of precursors from many different organic compounds. However, several studies have measured aldehydes in multiple weather conditions and found higher concentrations of many carbonyls downwind of roadways.[91,92] These findings suggest a substantial roadway source of these carbonyls.

In the past 20 years, many studies have been published with results reporting that populations who live, work, or go to school near high-traffic roadways experience higher rates of numerous adverse health effects, compared to populations far away from major roads.[93] In addition, numerous studies have found adverse health effects associated with spending time in traffic, such as commuting or walking along high-traffic roadways.[94,95,96,97] The health outcomes with the strongest evidence linking them with traffic-associated air pollutants are respiratory effects, particularly in asthmatic children, and cardiovascular effects.

Numerous reviews of this body of health literature have been published as well. In 2010, an expert panel of the Health Effects Institute (HEI) published a review of hundreds of exposure, epidemiology, and toxicology studies.[98] The panel rated how the evidence for each type of health outcome supported a conclusion of a causal association with traffic-associated air pollution as either "sufficient," "suggestive but not sufficient," or "inadequate and insufficient."

The panel categorized evidence of a causal association for exacerbation of childhood asthma as "sufficient." The panel categorized evidence of a causal association for new onset asthma as between "sufficient" and "suggestive but not sufficient." "Suggestive of a causal association" was how the panel categorized evidence linking traffic-associated air pollutants with exacerbation of adult respiratory symptoms and lung function decrement. It categorized as "inadequate and insufficient" evidence of a causal relationship between traffic-related air pollution and health care utilization for respiratory problems, new onset adult asthma, chronic obstructive pulmonary disease (COPD), nonasthmatic respiratory allergy, and cancer in adults and children. Currently, HEI is conducting another expert review of health studies associated with traffic-related air pollution published after the studies included in their 2010 review.[99] Other literature reviews have been published with conclusions generally similar to the 2010 HEI panel's.[100,101,102,103] However, in 2014, researchers from the U.S. Centers for Disease Control and Prevention (CDC) published a systematic review and meta-analysis of studies evaluating the risk of childhood leukemia associated with traffic exposure and reported positive associations between "postnatal" proximity to traffic and leukemia risks, but no such association for "prenatal" exposures.[104] The U.S. Department of Health and Human Services' National Toxicology Program (NTP) recently published a monograph including a systematic review of traffic-related air pollution (TRAP) and its impacts on hypertensive disorders of pregnancy. NTP concluded that exposure to TRAP is "presumed to be a hazard to pregnant women" for developing hypertensive disorders of pregnancy.[105]

Health outcomes with few publications suggest the possibility of other effects still lacking sufficient evidence to draw definitive conclusions. Among these outcomes with a small number of positive studies are neurological impacts (e.g., autism and reduced cognitive function) and reproductive outcomes (e.g., preterm birth, low birth weight).[106,107,108,109]

In addition to health outcomes, particularly cardiopulmonary effects, conclusions of numerous studies suggest mechanisms by which traffic-related air pollution affects health. Numerous studies indicate that near-roadway exposures may increase systemic inflammation, affecting organ systems, including blood vessels and lungs.[110,111,112,113] Long-term exposures in near-road environments have been associated with inflammation-associated conditions, such as atherosclerosis and asthma.[114,115,116]

Several studies suggest that some factors may increase susceptibility to the effects of traffic-associated air pollution. Several studies have found stronger respiratory associations in children experiencing chronic social stress, such as in violent neighborhoods or in homes with high family stress.[117,118,119]

The risks associated with residence, workplace, or schools near major roads are of potentially high public health significance due to the large population in such locations. Every two years from 1997 to 2009 and in 2011, the U.S. Census Bureau's American Housing Survey (AHS) conducted a survey that includes whether housing units are within 300 feet of an "airport, railroad, or highway with four or more lanes."[120] The 2013 AHS was the last AHS that included that question. The 2013 survey reports that 17.3 million housing units, or 13 percent of all housing units in the U.S., were in such areas. Assuming that populations and housing units are in the same locations, this corresponds to a population of more than 41 million U.S. residents in close proximity to high-traffic roadways or other transportation sources. According to the Central Intelligence Agency's World Factbook, based on data collected between 2012-2014, the

United States had 6,586,610 km of roadways, 293,564 km of railways, and 13,513 airports. As such, highways represent the overwhelming majority of transportation facilities described by this factor in the AHS.

On average, populations near major roads have higher fractions of minority residents and lower socioeconomic status (see Chapter 8.3).[121,122,123,124,125] Furthermore, on average, Americans spend more than an hour traveling each day, bringing nearly all residents into a high-exposure microenvironment for part of the day.[126]

7.1.3 <u>Environmental Effects Associated with Exposure to Non-GHG Pollutants</u>

7.1.3.1 Visibility

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[127] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. It is dominated by contributions from suspended particles except under pristine conditions. Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2019 PM ISA.[8]

EPA is working to address visibility impairment. Reductions in air pollution from implementation of various programs associated with the Clean Air Act Amendments of 1990 (CAAA) provisions have resulted in substantial improvements in visibility and will continue to do so in the future. Because trends in haze are closely associated with trends in particulate sulfate and nitrate due to the relationship between their concentration and light extinction, visibility trends have improved as emissions of SO_2 and NO_X have decreased over time due to air pollution regulations such as the Acid Rain Program.[8]

In the Clean Air Act Amendments of 1977, Congress recognized visibility's value to society by establishing a national goal to protect national parks and wilderness areas from visibility impairment caused by manmade pollution.[128] In 1999, EPA finalized the regional haze program to protect the visibility in Mandatory Class I Federal areas.[129] There are 156 national parks, forests and wilderness areas categorized as Mandatory Class I Federal areas.[130] These areas are defined in CAA Section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

EPA has also concluded that $PM_{2.5}$ causes adverse effects on visibility in other areas that are not targeted by the Regional Haze Rule, such as urban areas, depending on $PM_{2.5}$ concentrations and other factors such as dry chemical composition and relative humidity (i.e., an indicator of the water composition of the particles). EPA revised the $PM_{2.5}$ NAAQS in 2012, retained it in 2020, and established a target level of protection that is expected to be met through attainment of the existing secondary standards for $PM_{2.5}$.[131]

7.1.3.2 Ozone Effects on Ecosystems

The welfare effects of ozone include effects on ecosystems, which can be observed across a variety of scales, i.e., subcellular, cellular, leaf, whole plant, population, and ecosystem. Ozone effects that begin at small spatial scales, such as the leaf of an individual plant, when they occur at sufficient magnitudes (or to a sufficient degree) can result in effects being propagated along a continuum to higher and higher levels of biological organization. For example, effects at the individual plant level, such as altered rates of leaf gas exchange, growth and reproduction, can, when widespread, result in broad changes in ecosystems, such as productivity, carbon storage, water cycling, nutrient cycling, and community composition.

Ozone can produce both acute and chronic injury in sensitive plant species depending on the concentration level and the duration of the exposure.[132] In those sensitive species,[133] effects from repeated exposure to ozone throughout the growing season of the plant can tend to accumulate, so that even relatively low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation.[134,135] Ozone damage to sensitive plant species includes impaired photosynthesis and visible injury to leaves. The impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to reduced crop yields, timber production, and plant productivity and growth. Impaired photosynthesis can also lead to a reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.[136] These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on areas with sensitive species could potentially lead to species shifts and loss from the affected ecosystems,[137] resulting in a loss or reduction in associated ecosystem goods and services. Additionally, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas and reduced use of sensitive ornamentals in landscaping.[138] In addition to ozone effects on vegetation, newer evidence suggests that ozone affects interactions between plants and insects by altering chemical signals (e.g., floral scents) that plants use to communicate to other community members, such as attraction of pollinators.

The Ozone ISA presents more detailed information on how ozone affects vegetation and ecosystems.[13] The Ozone ISA reports causal and likely causal relationships between ozone exposure and a number of welfare effects and characterizes the weight of evidence for different effects associated with ozone.[e] The ISA concludes that visible foliar injury effects on vegetation, reduced vegetation growth, reduced plant reproduction, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops, alteration of below-ground biogeochemical cycles, and altered terrestrial community composition are causally associated with exposure to ozone. It also concludes that increased tree mortality, altered herbivore growth and reproduction, altered plant-insect signaling, reduced carbon sequestration in terrestrial ecosystems, and alteration of terrestrial ecosystem water cycling are likely to be causally associated with exposure to ozone.

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[e] The Ozone ISA evaluates the evidence associated with different ozone related health and welfare effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II of the ISA.

7.1.3.3 Deposition

The Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter - Ecological Criteria documents the ecological effects of the deposition of these criteria air pollutants.[139] It is clear from the body of evidence that oxides of nitrogen, oxides of sulfur, and particulate matter contribute to total nitrogen (N) and sulfur (S) deposition. In turn, N and S deposition cause either nutrient enrichment or acidification depending on the sensitivity of the landscape or the species in question. Both enrichment and acidification are characterized by an alteration of the biogeochemistry and the physiology of organisms, resulting in harmful declines in biodiversity in terrestrial, freshwater, wetland, and estuarine ecosystems in the U.S. Decreases in biodiversity mean that some species become relatively less abundant and may be locally extirpated. In addition to the loss of unique living species, the decline in total biodiversity can be harmful because biodiversity is an important determinant of the stability of ecosystems and their ability to provide socially valuable ecosystem services.

Terrestrial, wetland, freshwater, and estuarine ecosystems in the U.S. are affected by nitrogen enrichment/eutrophication caused by nitrogen deposition. These effects have been consistently documented across the U.S. for hundreds of species. In aquatic systems increased nitrogen can alter species assemblages and cause eutrophication. In terrestrial systems nitrogen loading can lead to loss of nitrogen-sensitive lichen species, decreased biodiversity of grasslands, meadows and other sensitive habitats, and increased potential for invasive species.

The sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is predominantly governed by geology. Prolonged exposure to excess nitrogen and sulfur deposition in sensitive areas acidifies lakes, rivers and soils. Increased acidity in surface waters creates inhospitable conditions for biota and affects the abundance and biodiversity of fishes, zooplankton and macroinvertebrates and ecosystem function. Over time, acidifying deposition also removes essential nutrients from forest soils, depleting the capacity of soils to neutralize future acid loadings and negatively affecting forest sustainability. Major effects in forests include a decline in sensitive tree species, such as red spruce (Picea rubens) and sugar maple (Acer saccharum).

Building materials including metals, stones, cements, and paints undergo natural weathering processes from exposure to environmental elements (e.g., wind, moisture, temperature fluctuations, sunlight, etc.). Pollution can worsen and accelerate these effects. Deposition of PM is associated with both physical damage (materials damage effects) and impaired aesthetic qualities (soiling effects). Wet and dry deposition of PM can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints and by deteriorating building materials such as stone, concrete and marble.[140] The effects of PM are exacerbated by the presence of acidic gases and can be additive or synergistic due to the complex mixture of pollutants in the air and surface characteristics of the material. Acidic deposition has been shown to have an effect on materials including zinc/galvanized steel and other metal, carbonate stone (as monuments and building facings), and surface coatings (paints).[141] The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects. In addition to aesthetic and functional effects on metals, stone and glass, altered energy efficiency of photovoltaic panels by PM deposition is also becoming an important consideration for impacts of air pollutants on materials.

7.1.3.4 Environmental Effects of Air Toxics

Emissions from producing, transporting and combusting fuel contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. Volatile organic compounds (VOCs), some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[142] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[143] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (e.g., acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[144]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[145,146,147] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

7.2 Non-GHG Monetized Health Benefits

It is important to quantify the health and environmental impacts associated with the revised program because a failure to adequately consider ancillary impacts could lead to an incorrect assessment of a program’s costs and benefits. Moreover, the health and other impacts of exposure to criteria air pollutants and airborne toxics tend to occur in the near term, while most effects from reduced climate change are likely to occur only over a time frame of several decades or longer. Ideally, human health benefits would be estimated based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, the projected non-GHG emissions impacts associated with the final rule will be expected to contribute to only very small changes in ambient air quality (see Preamble Section V.C for more detail). EPA intends to develop a future rule to control emissions of GHGs, criteria pollutants, and air toxic pollutants from light-duty vehicles for model years beyond 2026. We are considering how to project air quality impacts, and associated health benefits, from the changes in non-GHG emissions for that future rulemaking.

In lieu of air quality modeling, we use a reduced-form benefit-per-ton (BPT) approach to inform our assessment of health impacts, which is conceptually consistent with EPA’s use of BPT estimates in several previous RIAs.[148, 149] In this approach, the $PM_{2.5}$-related BPT values are the total monetized human health benefits (the sum of the economic value of the reduced risk of premature death and illness) that are expected from reducing one ton of directly-emitted $PM_{2.5}$ or $PM_{2.5}$ precursor such as NO_X or SO_2. We note, however, that the complex, non-linear photochemical processes that govern ozone formation prevent us from developing reduced-form ozone BPT values for mobile sources. This is an important limitation to recognize when using the BPT approach.

For tailpipe emissions, we apply national $PM_{2.5}$-related BPT values that were recently derived for the "Onroad Light-duty Vehicle" sector.[150,f] The onroad light-duty vehicle BPT values were derived using detailed mobile sector source-apportionment air quality modeling, and apply EPA's existing method for using reduced-form tools to estimate $PM_{2.5}$ -related benefits.[151,152]

To monetize the $PM_{2.5}$-related impacts of upstream emissions, we apply BPT values that were developed for the refinery and electric generating unit (EGU) sectors.[153] While upstream emissions also include petroleum extraction, storage and transport sources, as well as sources upstream from the refinery, the modeling tool used to support this analysis only provides estimates of upstream emissions impacts aggregated across refinery and EGU sources. We believe for purposes of this rule the separate accounting of refinery and EGU impacts adequately monetizes upstream PM-related health impacts.

EPA bases its benefits analyses on peer-reviewed studies of air quality and health effects and peer-reviewed studies of the monetary values of public health and welfare improvements. Very recently, EPA updated its approach to estimating the benefits of changes in $PM_{2.5}$ and ozone.[154,155] These updates were based on information drawn from the recent 2019 $PM_{2.5}$ and 2020 Ozone Integrated Science Assessments (ISAs), which were reviewed by the Clean Air Science Advisory Committee (CASAC) and the public.[156,157] As part of the update, EPA identified $PM_{2.5}$-related long-term premature mortality risk estimates from two studies deemed most appropriate to inform a benefits analysis: a retrospective analysis of Medicare beneficiaries (Medicare) and the American Cancer Society Cancer Prevention II study (ACS CPS-II).[158,159,g]

EPA has not updated its mobile source BPT estimates to reflect these updates in time for this analysis. Instead, we use $PM_{2.5}$ BPT estimates that are based on the review of the 2009 PM ISA[160] and 2012 PM ISA Provisional Assessment[161] and include a mortality risk estimate derived from the Krewski et al. (2009)[162] analysis of the ACS CPS-II cohort and nonfatal illnesses consistent with benefits analyses performed for the analysis of the final Tier 3 Vehicle Rule,[163] the final 2012 PM NAAQS Revision,[164] and the final 2017-2025 Light-duty Vehicle GHG Rule.[165] We expect this lag in updating our BPT estimates to have only a small impact on total PM benefits, since the underlying mortality risk estimate based on the Krewski study is identical to the updated $PM_{2.5}$ mortality risk estimate derived from an expanded analysis of the same ACS CPS-II cohort.[166] The Agency is currently working to update its mobile source BPT estimates to reflect these recent updates for use in future rulemaking analyses.

Table 7-1 and Table 7-2 displays the health effects associated with human exposure to ambient concentrations of $PM_{2.5}$ and ozone, respectively, including the quantified $PM_{2.5}$-related benefits included in the BPT estimates used in this analysis and the unquantified $PM_{2.5}$ and ozone health effects the BPT estimates do not capture. Table 7-3 also displays additional criteria pollutant-related health and environmental effects not captured in the BPT estimates.

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[f] Available for download here: https://www.epa.gov/benmap/mobile-sector-source-apportionment-air-quality-and-benefits-ton.

[g] The Harvard Six Cities Study (Lepeule et al., 2012), which had been identified for use in estimating mortality impacts in previous PM benefits analyses, was not identified as most appropriate for the benefits update due to geographic limitations.

Table 7-1: Health Effects of Ambient $PM_{2.5}$

Category	Effect	Effect Quantified	Effect Monetized	More Information
Premature mortality from exposure to $PM_{2.5}$	Adult premature mortality from long-term exposure (age 25-99 or age 30-99)	✓	✓	2009/2012 PM ISA[167,168]
	Infant mortality (age <1)	✓	✓	2009/2012 PM ISA
	Adult premature mortality from long-term exposure (age 65-99)	—	—	2019 PM ISA[169]
Nonfatal morbidity from exposure to $PM_{2.5}$	Non-fatal heart attacks (age > 18)	✓	✓	2009/2012 PM ISA
	Hospital admissions – respiratory (all ages)	✓	✓	2009/2012 PM ISA
	Hospital admissions – cardiovascular (age > 20)	✓	✓	2009/2012 PM ISA
	Emergency department visits—respiratory (all ages)	✓	✓	2009/2012 PM ISA
	Acute bronchitis (age 8-12)	✓	✓	2009/2012 PM ISA
	Lower respiratory symptoms (age 7-14)	✓	✓	2009/2012 PM ISA
	Upper respiratory symptoms (asthmatics age 9-11)	✓	✓	2009/2012 PM ISA
	Asthma exacerbation (asthmatics age 6-18)	✓	✓	2009/2012 PM ISA
	Lost work days (age 18-65)	✓	✓	2009/2012 PM ISA
	Minor restricted-activity days (age 18-65)	✓	✓	2009/2012 PM ISA
	Hospital admissions—cardiovascular (ages 65-99)	—	—	2019 PM ISA
	Emergency department visits— cardiovascular (age 0-99)	—	—	2019 PM ISA
	Hospital admissions—respiratory (ages 0-18 and 65-99)	—	—	2019 PM ISA
	Cardiac arrest (ages 0-99; excludes initial hospital and/or emergency department visits)	—	—	2019 PM ISA
	Stroke (ages 65-99)	—	—	2019 PM ISA
	Asthma onset (ages 0-17)	—	—	2019 PM ISA
	Asthma symptoms/exacerbation (6-17)	—	—	2019 PM ISA
	Lung cancer (ages 30-99)	—	—	2019 PM ISA
	Allergic rhinitis (hay fever) symptoms (ages 3-17)	—	—	2019 PM ISA
	Hospital admissions—Alzheimer’s disease (ages 65-99)	—	—	2019 PM ISA
	Hospital admissions—Parkinson’s disease (ages 65-99)	—	—	2019 PM ISA
	Other cardiovascular effects (e.g., other ages)	—	—	2019 PM ISA
	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)	—	—	2019 PM ISA
	Other nervous system effects (e.g., autism, cognitive decline, dementia)	—	—	2019 PM ISA
	Metabolic effects (e.g., diabetes)	—	—	2019 PM ISA
	Reproductive and developmental effects (e.g., low birth weight, pre-term births, etc.)	—	—	2019 PM ISA
	Cancer, mutagenicity, and genotoxicity effects	—	—	2019 PM ISA

Table 7-2: Health Effects of Ambient Ozone

Mortality from exposure to ozone	Premature respiratory mortality from short-term exposure (0-99)	—	—	2020 Ozone ISA[170]
	Premature respiratory mortality from long-term exposure (age 30–99)	—	—	2020 Ozone ISA
Nonfatal morbidity from exposure to ozone	Hospital admissions—respiratory (ages 65-99)	—	—	2020 Ozone ISA
	Emergency department visits—respiratory (ages 0-99)	—	—	2020 Ozone ISA
	Asthma onset (0-17)	—	—	2020 Ozone ISA
	Asthma symptoms/exacerbation (asthmatics age 5-17)	—	—	2020 Ozone ISA
	Allergic rhinitis (hay fever) symptoms (ages 3-17)	—	—	2020 Ozone ISA
	Minor restricted-activity days (age 18–65)	—	—	2020 Ozone ISA
	School absence days (age 5–17)	—	—	2020 Ozone ISA
	Decreased outdoor worker productivity (age 18–65)	—	—	2020 Ozone ISA
	Metabolic effects (e.g., diabetes)	—	—	2020 Ozone ISA
	Other respiratory effects (e.g., premature aging of lungs)	—	—	2020 Ozone ISA
	Cardiovascular and nervous system effects	—	—	2020 Ozone ISA
	Reproductive and developmental effects	—	—	2020 Ozone ISA

Table 7-3: Additional Unquantified Health and Welfare Benefits Categories

Category	Effect	Effect Quantified	Effect Monetized	More Information
Improved Human Health				
Reduced incidence of morbidity from exposure to NO2	Asthma hospital admissions	—	—	2016 NO2 ISA[171]
	Chronic lung disease hospital admissions	—	—	2016NO2 ISA
	Respiratory emergency department visits	—	—	2016 NO2 ISA
	Asthma exacerbation	—	—	2016 NO2 ISA
	Acute respiratory symptoms	—	—	2016 NO2 ISA
	Premature mortality	—	—	2016 NO2 ISA
	Other respiratory effects (e.g., airway hyperresponsiveness and inflammation, lung function, other ages and populations)	—	—	2016 NO2 ISA
Improved Environment				
Reduced visibility impairment	Visibility in Class 1 areas	—	—	2019 PM ISA
	Visibility in residential areas	—	—	2019 PM ISA
Reduced effects on materials	Household soiling	—	—	2019 PM ISA
	Materials damage (e.g., corrosion, increased wear)	—	—	2019 PM ISA
Reduced effects from PM deposition (metals and organics)	Effects on Individual organisms and ecosystems	—	—	2019 PM ISA
Reduced vegetation and ecosystem effects from exposure to ozone	Visible foliar injury on vegetation	—	—	2020 Ozone ISA
	Reduced vegetation growth and reproduction	—	—	2020 Ozone ISA
	Yield and quality of commercial forest products and crops	—	—	2020 Ozone ISA
	Damage to urban ornamental plants	—	—	2020 Ozone ISA
	Carbon sequestration in terrestrial ecosystems	—	—	2020 Ozone ISA
	Recreational demand associated with forest aesthetics	—	—	2020 Ozone ISA
	Other non-use effects			2020 Ozone ISA
	Ecosystem functions (e.g., water cycling, biogeochemical cycles, net primary productivity, leaf-gas exchange, community composition)	—	—	2020 Ozone ISA
Reduced effects from acid deposition	Recreational fishing	—	—	2008 NO_X SO_X ISA[172]
	Tree mortality and decline	—	—	2008 NO_X SO_X ISA
	Commercial fishing and forestry effects	—	—	2008 NO_X SO_X ISA
	Recreational demand in terrestrial and aquatic ecosystems	—	—	2008 NO_X SO_X ISA
	Other non-use effects			2008 NO_X SO_X ISA
	Ecosystem functions (e.g., biogeochemical cycles)	—	—	2008 NO_X SO_X ISA
Reduced effects from nutrient enrichment	Species composition and biodiversity in terrestrial and estuarine ecosystems	—	—	2008 NO_X SO_X ISA
	Coastal eutrophication	—	—	2008 NO_X SO_X ISA
	Recreational demand in terrestrial and estuarine ecosystems	—	—	2008 NO_X SO_X ISA
	Other non-use effects			2008 NO_X SO_X ISA
	Ecosystem functions (e.g., biogeochemical cycles, fire regulation)	—	—	2008 NO_X SO_X ISA
Reduced vegetation effects from ambient exposure to SO_2 and NO_X	Injury to vegetation from SO_2 exposure	—	—	2008 NO_X SO_X ISA
	Injury to vegetation from NO_X exposure	—	—	2008 NO_X SO_X ISA

In addition to omitting ozone-related impacts from this analysis, there are other impacts associated with reductions in exposure to NO_2, ecosystem benefits, and visibility improvement that EPA is unable to quantify due to data, resource, and methodological limitations. Chapter 7.1 provides a qualitative description of both the health and environmental effects of the criteria pollutants controlled by the revised program.

There would also be impacts associated with reductions in air toxic pollutant emissions that result from the final program (see Chapters 5.1 and 7.1), but the Agency does not attempt to monetize those impacts. This is because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimation or benefits assessment. While EPA has worked to improve these tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics.

The PM-related BPT estimates used in this analysis are provided in Table 7-4. We multiply these BPT values by national changes in projected NO_X, SO_2 and directly-emitted $PM_{2.5}$, in tons, to estimate the total $PM_{2.5}$-related monetized human health benefits associated with the final program. As the table indicates, these values differ among pollutants and depend on their original source, because emissions from different sources can result in different degrees of population exposure and resulting health impacts. The BPT values for emissions of non-GHG pollutants from both onroad light-duty vehicle use and upstream sources such as fuel refineries will increase over time. These projected increases reflect rising income levels, which increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution. The BPT values also reflect future population growth and increased life expectancy, which expands the size of the population exposed to air pollution in both urban and rural areas, especially among older age groups with the highest mortality risk.[173]

Table 7-5 through Table 7-7 display the total undiscounted stream of $PM_{2.5}$-related benefits and the present value of those benefits for the final rule and two alternatives. Using $PM_{2.5}$-related BPT estimates to monetize the non-GHG impacts of the final standards omits ozone-related impacts as well as other impacts associated with reductions in exposure to air toxics, ecosystem benefits, and visibility improvement. RIA Chapter 7.1 provides a qualitative description of both the health and environmental effects of the non-GHG pollutants impacted by the final program.

Table 7-4: PM-related Benefit-per-ton Values (2018$)[a]

Year	Onroad Light-duty Vehicles[b]			Upstream Sources - Refineries[c]			Upstream Sources - EGUs[c]		
	Direct $PM_{2.5}$	SO_2	NO_X	Direct $PM_{2.5}$	SO_2	NO_X	Direct $PM_{2.5}$	SO_2	NO_X
Estimated Using a 3 Percent Discount Rate									
2020	$600,000	$150,000	$6,400	$380,000	$81,000	$8,100	$160,000	$44,000	$6,600
2025	$660,000	$170,000	$6,900	$420,000	$90,000	$8,800	$180,000	$49,000	$7,100
2030	$740,000	$190,000	$7,600	$450,000	$98,000	$9,600	$190,000	$52,000	$7,600
2035	$830,000	$210,000	$8,400	-	-	-	-	-	-
2040	$920,000	$230,000	$9,000	-	-	-	-	-	-
2045	$1,000,000	$250,000	$9,600	-	-	-	-	-	-
Estimated Using a 7 Percent Discount Rate									
2020	$540,000	$140,000	$5,800	$350,000	$74,000	$7,300	$150,000	$40,000	$5,900
2025	$600,000	$150,000	$6,200	$380,000	$80,000	$7,900	$160,000	$43,000	$6,400
2030	$660,000	$170,000	$6,800	$410,000	$88,000	$8,600	$170,000	$48,000	$6,900
2035	$750,000	$190,000	$7,500	-	-	-	-	-	-
2040	$830,000	$210,000	$8,200	-	-	-	-	-	-
2045	$900,000	$230,000	$8,600	-	-	-	-	-	-

Notes:

[a] The benefit-per-ton estimates presented in this table are based on estimates derived from the American Cancer Society cohort study (Krewski et al., 2009). They also assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented premature mortality cessation lag.

[b] Benefit-per-ton values for onroad light-duty vehicles were estimated for the years 2020, 2025, 2030, 2035, 2040, and 2045. We hold values constant for intervening years (e.g., the 2020 values are assumed to apply to years 2021-2024; 2025 values for years 2026-2029; and 2045 values for years 2046 and beyond).

[c] Benefit-per-ton values for upstream sources were estimated only for the years 2020, 2025 and 2030. We hold values constant for intervening years and 2030 values are applied to years 2031 and beyond.

Table 7-5: Undiscounted Stream, Present and Annualized Value of $PM_{2.5}$-related Benefits from 2023 through 2050 for the Final Rule (Discounted at 3 percent and 7 percent; $Billions of 2018$)[a]

Calendar Year	Tailpipe		Upstream		Total	
	3% DR	7% DR	3% DR	7% DR	3% DR	7% DR
2023	-$0.0034	-$0.0031	$0.02	$0.018	$0.016	$0.015
2024	-$0.0012	-$0.0011	$0.026	$0.024	$0.025	$0.023
2025	$0.0057	$0.0051	$0.054	$0.05	$0.06	$0.055
2026	$0.018	$0.016	$0.097	$0.088	$0.11	$0.1
2027	$0.036	$0.032	$0.18	$0.16	$0.21	$0.19
2028	$0.063	$0.057	$0.27	$0.25	$0.34	$0.3
2029	$0.095	$0.086	$0.34	$0.31	$0.44	$0.4
2030	$0.15	$0.13	$0.45	$0.41	$0.6	$0.54
2031	$0.19	$0.17	$0.52	$0.47	$0.71	$0.64
2032	$0.23	$0.21	$0.59	$0.54	$0.82	$0.74
2033	$0.27	$0.24	$0.65	$0.59	$0.92	$0.83
2034	$0.31	$0.28	$0.72	$0.66	$1	$0.93
2035	$0.44	$0.4	$0.79	$0.72	$1.2	$1.1
2036	$0.48	$0.44	$0.85	$0.77	$1.3	$1.2
2037	$0.52	$0.47	$0.9	$0.82	$1.4	$1.3
2038	$0.56	$0.5	$0.95	$0.86	$1.5	$1.4
2039	$0.59	$0.53	$1	$0.91	$1.6	$1.4
2040	$0.68	$0.62	$1	$0.95	$1.7	$1.6
2041	$0.71	$0.64	$1.1	$0.99	$1.8	$1.6
2042	$0.73	$0.66	$1.1	$1	$1.9	$1.7
2043	$0.75	$0.68	$1.2	$1.1	$1.9	$1.7
2044	$0.77	$0.69	$1.2	$1.1	$2	$1.8
2045	$0.85	$0.77	$1.2	$1.1	$2.1	$1.9
2046	$0.86	$0.78	$1.3	$1.2	$2.1	$1.9
2047	$0.87	$0.79	$1.3	$1.2	$2.2	$2
2048	$0.88	$0.79	$1.3	$1.2	$2.2	$2
2049	$0.88	$0.8	$1.4	$1.2	$2.3	$2
2050	$0.89	$0.8	$1.4	$1.3	$2.3	$2.1
PV	$6.7	$2.8	$12	$5.3	$19	$8.1
Annualized	$0.34	$0.22	$0.61	$0.43	$0.96	$0.65

Notes:

[a] Note that the non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

[b] Calendar year non-GHG benefits presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of PM-related premature mortality to account for a twenty-year segmented cessation lag. Note that annual benefits estimated using a 3 percent discount rate were used to calculate the present and annualized values using a 3 percent discount rate and the annual benefits estimated using a 7 percent discount rate were used to calculate the present and annualized values using a 7 percent discount rate.

Table 7-6: Undiscounted Stream, Present and Annualized Value of $PM_{2.5}$-related Benefits from 2023 through 2050 for the Proposal (Discounted at 3 percent and 7 percent; $Billions of 2018$)[a]

Calendar Year	Tailpipe		Upstream		Total	
	3% DR	7% DR	3% DR	7% DR	3% DR	7% DR
2023	-$0.0023	-$0.0021	$0.0017	$0.0016	-$0.00061	-$0.00053
2024	-$0.0014	-$0.0013	$0.00021	$0.00019	-$0.0012	-$0.0011
2025	$0.0059	$0.0053	$0.015	$0.015	$0.021	$0.02
2026	$0.012	$0.011	$0.048	$0.045	$0.061	$0.056
2027	$0.029	$0.026	$0.11	$0.096	$0.13	$0.12
2028	$0.047	$0.043	$0.17	$0.16	$0.22	$0.2
2029	$0.069	$0.063	$0.22	$0.2	$0.29	$0.26
2030	$0.1	$0.094	$0.29	$0.27	$0.4	$0.36
2031	$0.13	$0.12	$0.34	$0.31	$0.47	$0.43
2032	$0.15	$0.14	$0.39	$0.35	$0.54	$0.49
2033	$0.18	$0.16	$0.43	$0.39	$0.61	$0.55
2034	$0.2	$0.18	$0.47	$0.43	$0.68	$0.61
2035	$0.29	$0.26	$0.52	$0.47	$0.81	$0.73
2036	$0.31	$0.28	$0.56	$0.51	$0.87	$0.79
2037	$0.34	$0.3	$0.59	$0.54	$0.93	$0.84
2038	$0.36	$0.32	$0.62	$0.56	$0.98	$0.88
2039	$0.37	$0.34	$0.65	$0.59	$1	$0.93
2040	$0.43	$0.39	$0.68	$0.62	$1.1	$1
2041	$0.45	$0.4	$0.71	$0.64	$1.2	$1
2042	$0.46	$0.42	$0.73	$0.66	$1.2	$1.1
2043	$0.47	$0.43	$0.75	$0.68	$1.2	$1.1
2044	$0.48	$0.44	$0.78	$0.7	$1.3	$1.1
2045	$0.54	$0.48	$0.8	$0.72	$1.3	$1.2
2046	$0.54	$0.49	$0.82	$0.74	$1.4	$1.2
2047	$0.55	$0.5	$0.84	$0.76	$1.4	$1.3
2048	$0.55	$0.5	$0.85	$0.77	$1.4	$1.3
2049	$0.56	$0.5	$0.88	$0.8	$1.4	$1.3
2050	$0.56	$0.51	$0.91	$0.82	$1.5	$1.3
PV	$4.3	$1.8	$7.7	$3.4	$12	$5.2
Annualized	$0.22	$0.14	$0.39	$0.27	$0.61	$0.42

Notes:
[a] Note that the non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.
[b] Calendar year non-GHG benefits presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of PM-related premature mortality to account for a twenty-year segmented cessation lag. Note that annual benefits estimated using a 3 percent discount rate were used to calculate the present and annualized values using a 3 percent discount rate and the annual benefits estimated using a 7 percent discount rate were used to calculate the present and annualized values using a 7 percent discount rate.

Table 7-7: Undiscounted Stream, Present and Annualized Value of $PM_{2.5}$-related Benefits from 2023 through 2050 for Alternative 2 minus 10 (Discounted at 3 percent and 7 percent; $Billions of 2018$)[a]

Calendar Year	Tailpipe		Upstream		Total	
	3% DR	7% DR	3% DR	7% DR	3% DR	7% DR
2023	-$0.0076	-$0.0068	$0.031	$0.028	$0.023	$0.021
2024	-$0.0083	-$0.0075	$0.05	$0.046	$0.041	$0.038
2025	-$0.00018	-$0.00016	$0.095	$0.087	$0.095	$0.087
2026	$0.018	$0.016	$0.15	$0.13	$0.17	$0.15
2027	$0.037	$0.034	$0.23	$0.21	$0.27	$0.24
2028	$0.069	$0.062	$0.33	$0.29	$0.39	$0.36
2029	$0.1	$0.092	$0.39	$0.35	$0.49	$0.45
2030	$0.16	$0.14	$0.5	$0.45	$0.66	$0.6
2031	$0.2	$0.18	$0.56	$0.51	$0.77	$0.69
2032	$0.24	$0.22	$0.63	$0.57	$0.87	$0.79
2033	$0.28	$0.26	$0.68	$0.62	$0.97	$0.88
2034	$0.32	$0.29	$0.75	$0.68	$1.1	$0.97
2035	$0.46	$0.42	$0.81	$0.74	$1.3	$1.2
2036	$0.51	$0.46	$0.87	$0.79	$1.4	$1.2
2037	$0.54	$0.49	$0.92	$0.83	$1.5	$1.3
2038	$0.58	$0.52	$0.96	$0.87	$1.5	$1.4
2039	$0.61	$0.55	$1	$0.91	$1.6	$1.5
2040	$0.71	$0.64	$1.1	$0.95	$1.8	$1.6
2041	$0.73	$0.66	$1.1	$0.99	$1.8	$1.7
2042	$0.76	$0.68	$1.1	$1	$1.9	$1.7
2043	$0.78	$0.7	$1.2	$1.1	$1.9	$1.8
2044	$0.79	$0.71	$1.2	$1.1	$2	$1.8
2045	$0.88	$0.79	$1.2	$1.1	$2.1	$1.9
2046	$0.89	$0.8	$1.3	$1.1	$2.2	$1.9
2047	$0.9	$0.81	$1.3	$1.2	$2.2	$2
2048	$0.91	$0.82	$1.3	$1.2	$2.2	$2
2049	$0.92	$0.83	$1.4	$1.2	$2.3	$2.1
2050	$0.93	$0.84	$1.4	$1.3	$2.3	$2.1
PV	$7	$2.9	$12	$5.5	$19	$8.4
Annualized	$0.36	$0.23	$0.63	$0.45	$0.99	$0.68

Notes:
[a] Note that the non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.
[b] Calendar year non-GHG benefits presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of PM-related premature mortality to account for a twenty-year segmented cessation lag. Note that annual benefits estimated using a 3 percent discount rate were used to calculate the present and annualized values using a 3 percent discount rate and the annual benefits estimated using a 7 percent discount rate were used to calculate the present and annualized values using a 7 percent discount rate.

7.2.1 <u>Uncertainty</u>

Uncertainties and limitations exist at each stage of the emissions-to-health benefit analysis pathway (e.g., projected emissions inventories, air quality modeling, health impact assessment, economic valuation). The BPT approach to monetizing benefits relies on many assumptions;

when uncertainties associated with these assumptions are compounded, even small uncertainties can greatly influence the size of the total quantified benefits. Some key assumptions associated with $PM_{2.5}$-related health benefits and uncertainties associated with the BPT approach are described below.

We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. Support for this assumption comes from the 2019 PM ISA, which concluded that “many $PM_{2.5}$ components and sources are associated with many health effects and that the evidence does not indicate that any one source or component is consistently more strongly related with health effects than $PM_{2.5}$ mass."[174]

We assume that the health impact function for fine particles is log-linear without a threshold. Thus, the estimates include health benefits from reducing fine particles in areas with different concentrations of $PM_{2.5}$, including both areas with projected annual mean concentrations that are above the level of the fine particle standard and areas with projected concentrations below the level of the standard.

We also assume that there is a “cessation” lag between the change in PM exposures and the total realization of changes in mortality effects. Specifically, we assume that some of the incidences of premature mortality related to $PM_{2.5}$ exposures occur in a distributed fashion over the 20 years following exposure based on the advice of the Science Advisory Board Health Effect Subcommittee,[175] which affects the valuation of mortality benefits at different discount rates. The above assumptions are subject to uncertainty.

In general, we are more confident in the magnitude of the risks we estimate from simulated $PM_{2.5}$ concentrations that coincide with the bulk of the observed PM concentrations in the epidemiological studies that are used to estimate the benefits. Likewise, we are less confident in the risk we estimate from simulated $PM_{2.5}$ concentrations that fall below the bulk of the observed data in these studies. There are uncertainties inherent in identifying any particular point at which our confidence in reported associations decreases appreciably, and the scientific evidence provides no clear dividing line. Applying BPT values to estimates of changes in policy-related emissions precludes us from assessing the distribution of risk as it relates to the associated distribution of baseline concentrations of $PM_{2.5}$.

Another limitation of using the BPT approach is an inability to provide estimates of the health benefits associated with exposure to ozone, ambient NO_X, and air toxics. Furthermore, the air quality modeling that underlies the $PM_{2.5}$ BPT value did not provide estimates of the $PM_{2.5}$-related benefits associated with reducing VOC emissions, but these unquantified benefits are generally small compared to benefits associated with other $PM_{2.5}$ precursors.[176]

National-average BPT values reflect the geographic distribution of the underlying modeled emissions used in their calculation, which may not exactly match the geographic distribution of the emission reductions that would occur due to a specific rulemaking. Similarly, BPT estimates may not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors for any specific location. For instance, even though we assume that all fine particles have equivalent health effects, the BPT estimates vary across precursors depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drives population exposure. The emissions and photochemically-modeled $PM_{2.5}$ concentrations used to derive the BPT values may not match the changes in air quality that would result from the final rule.

Finally, as mentioned earlier in this chapter, EPA recently updated its approach to estimating the benefits of changes in $PM_{2.5}$ and ozone. EPA has not had an opportunity to update its mobile source BPT estimates to reflect these updates in time for this analysis. The Agency is currently working to update its BPT estimates to reflect these changes for use in future rulemaking analyses.

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[12] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notably different ozone concentrations. Also, the amount of ozone delivered to the lung is influenced not only by the ambient concentrations but also by the breathing route and rate.

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[14] The ISA evaluates evidence and draws conclusions on the causal relationship between relevant pollutant exposures and health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II in the Preamble of the ISA.

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[19] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

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Chapter 8: Vehicle Sales, Employment, Environmental Justice, and Affordability and Equity Impacts

8.1 Sales Impacts

8.1.1 Conceptual Framework

A significant question in vehicle GHG rules has been why there have appeared to be existing technologies that, if adopted, would reduce fuel consumption enough to pay for themselves in short periods, but which were not widely adopted. If the benefits to vehicle buyers outweighed the costs to those buyers of the new technologies, economic principles suggest that automakers would provide them, and people would buy them. Yet engineering analyses have identified a number of technologies, such as downsized-turbocharged engines, gasoline direct injection, and improved aerodynamics, with short payback periods that were not widely adopted before the standards, but which were adopted rapidly afterwards.[1] Why did markets fail, on their own, to adopt these technologies?

This question, termed the "energy paradox" or "energy efficiency gap,"[2] has received a great deal of discussion in previous rulemakings.[3] The gap exists if the estimates of net benefits of these new technologies are correct, and if there are no major adverse effects associated with the technologies (hidden costs) that provide clear disincentives to adopt the technologies. A separate question is to explain why the gap exists.

8.1.1.1 Existence of the Energy Efficiency Gap

EPA has previously explored the existence of the paradox, including in the Midterm Evaluation.[4] In terms of the costs and effectiveness of the fuel-saving technologies, EPA has relied on published research, highly-regarded teardown studies,[5] and extensive testing to ensure the best available estimates for its analyses. In the MTE's TAR and Proposed Determination TSD, EPA undertook retrospective analysis of its cost and effectiveness estimates and generally confirmed the previous estimates. See Chapter 4 of this RIA for more discussion of the technology and cost estimates for this rule.

The 2021 National Academies of Science (NAS) report[6] (p. 11-348) raises the issue of tradeoffs between improved performance and fuel economy and recommends that "agencies should collect further evidence on the influence of vehicle performance trade-offs on automaker compliance strategies and consumers, and reassess whether forgone performance improvements should be included in benefit-cost analysis of the standards. The agencies should assess how new technologies penetrating the market will affect the trade-offs among greenhouse gas (GHG) emissions rates, performance, and other attributes."

EPA has considered evidence related to potential adverse effects on other vehicle attributes. First, EPA sponsored research to evaluate how auto reviewers -- professionals expected to be especially sensitive to vehicle performance and attributes -- evaluated MY 2014 and 2015 vehicles with fuel-saving technologies (Helfand et al. 2016, Huang et al. 2018).[7] These studies found that all technologies were evaluated positively more often than they were evaluated negatively, suggesting that it is possible to implement these technologies without imposing hidden costs. In addition, they looked for correlations between evaluations of each technology and a range of operational characteristics (handling, acceleration, noise, etc.). Both papers found few correlations between the existence of a technology and negative rating of operational characteristics; and even fewer of those were consistently correlated in both model years. In addition, Huang et al. (2018) found that overall evaluation of a vehicle's quality is more associated with operational characteristics than with the technologies themselves; as noted in the previous paragraph, there is little association between operational characteristics and the technologies.

Additional research (Huang et al. 2018a)[8] explored the use of results from a consumer satisfaction survey conducted by Strategic Vision to look at how vehicle buyers responded to the presence of fuel-saving technologies. Preliminary results were developed using a subset of the data, due to incomplete matching of technology information with survey information. Overall, people were highly satisfied with their newly purchased vehicles; less than 3 percent of owners expressed dissatisfaction. This result is not surprising; people are unlikely to buy new vehicles that they find unsatisfactory. Further, comparing negative satisfaction ratings from before and after the presence of fuel saving technology, results show little correlation between the presence of a technology and a change in satisfaction ratings for overall experience, power and pickup, driving performance, noise/vibration/harshness, or fuel economy. EPA continues to explore these data.

In these three studies, a limitation is that it is not possible to demonstrate causally that the presence or absence of a technology affects people's perceptions of vehicle quality. For instance, it may be that some of the fuel-saving technologies are used primarily in market segments that would, regardless of the presence of the technology, not be considered as high-quality as vehicles in other market segments; an association between the presence of the technology and an evaluation of quality may be based, not on a causal effect of the technology on quality, but rather a correlation due to its use in that market segment. Nevertheless, the research indicates that it has been possible for these technologies to be adopted without observed adverse impacts on assessments by expert reviewers or on consumer satisfaction.

Some research[9] has argued that reducing fuel consumption must come at the expense of either vehicle acceleration or vehicle weight. The concept is based in the principle that energy is required to move the vehicle, so that heavier and faster vehicles will require more energy use. While this statement is true when all else (e.g., powertrain, body style) is held constant, it is uncommon that, in fact, all else is held constant. The Midterm Evaluation Proposed Determination TSD, Chapter 4.1.2, discussed some concerns and limitations with the existing literature. One issue is that the papers typically assume that the tradeoff between power and fuel economy, or between weight and fuel economy, does not vary over time. MacKenzie and Heywood (2015) further point out that these studies are based on horsepower and weight, two measures that may not accurately reflect the characteristics sought by vehicle buyers. If, as they have found, the relationship between acceleration (measured as 0-to-60 speed) and horsepower divided by weight has changed over time, then studies holding constant the relationship between horsepower-to-weight and fuel consumption are not accurately measuring the tradeoff of concern to vehicle buyers.

Recent work by Moskalik et al. (2018)[10] suggests that using historic data to estimate tradeoffs may miss changes in the relationship between acceleration and CO_2 emissions with new technologies. Moskalik et al. (2018) shows results using the ALPHA model for trade-off curves between CO_2 emissions and 0-to-60 acceleration time for five different engine types covering a range of production years: carbureted, port fuel injection (PFI), gasoline direct injection (GDI), Atkinson, and turbo-downsized (TDS) engines. These engines have different operating efficiency characteristics, and thus different tradeoff curves. Most notably, the newest TDS engines have much flatter tradeoffs than earlier carbureted, GDI and PFI; in fact, the "future" TDS engine shows almost no change in CO_2 emissions over a wide range of acceleration times. Thus, the assumption in the previous research that the tradeoffs among acceleration, fuel economy, and weight are constant does not appear to accurately represent the new technologies, and in fact may substantially overestimate the magnitude of the performance-fuel economy tradeoff.

Watten et al. (2021)[11] develops a theoretical framework that incorporates producer decisions on technological adoption and attribute production, taking into account consumer preferences toward performance and fuel economy. This paper distinguishes between technologies that improve, or do not adversely affect, both performance and fuel economy, and reducing engine displacement, which does trade off improved fuel economy for performance. Following Moskalik et al. (2018), it observes that the "marginal rate of attribute substitution" between power and fuel economy has changed substantially over time. In particular, it has become relatively more costly to improve efficiency by reducing power, and relatively less costly to add technologies that improve efficiency. These technology improvements do not reduce power and in some cases may increase it. It supports the concept that automakers take consumer preferences into account in identifying where to add technology.

Regarding the NAS's recommendation to evaluate whether forgone performance improvements should be included in the benefit-cost analysis, the agencies have typically included the costs of holding performance constant in the rulemakings. As discussed in previous paragraphs, ways exist to enhance performance without adverse effects on fuel economy. In that case, Helfand and Dorsey-Palmateer (2015)[12] argue that the only additional cost due to the standards associated with additional performance would occur if adding that performance is more expensive for a vehicle with higher fuel economy. In addition, it would be important to add benefits associated with improvements in other attributes due to fuel-saving technologies. As EPA has found in the past, many fuel-saving technologies can enhance performance, handling, or other attributes. Whitefoot et al. (2017)[13] find that allowing for tradeoffs between performance and fuel economy reduces the costs of the standards, by allowing an additional way to achieve compliance. EPA has not included either these potential changes in costs or increased benefits in its analysis, due to lack of sufficient data to estimate these effects. Recent technology trends and other evidence suggest that tradeoffs need not lead to forgone performance attributes; and, if manufacturers lower costs by reducing other attributes, EPA's constant-performance assumption results in a conservative estimate of the rule's overall compliance costs.

This discussion does not reject the observation that the energy efficiency gap has existed for light-duty vehicles. Cost and effectiveness values for the technologies have not been shown to have significant errors. Helfand and Dorsey-Palmateer (2015) conclude that, in response to the standards, automakers have improved fuel economy without adversely affecting other vehicle attributes, and any remaining tradeoffs are likely to be included in the costs of the technologies. Thus, it appears that markets on their own have not led to adoption of a number of technologies with short payback periods in the absence of the standards.

8.1.1.2 Potential Explanations for the Existence of the Energy Efficiency Gap

While EPA has documented the existence of the energy efficiency gap for provision of fuel-saving technologies, various hypotheses have been raised for the causes of that gap. Previous rules have discussed a number of these hypotheses for this apparent market failure.[14] Here we summarize a number of theories that have been suggested. Researchers and some commenters use different names and organizational principles in defining these theories. As a result, this list may not seem complete to all.

On the consumer side, the 2021 NAS Report (p. 11-355) observes that "the literature has not settled on a single explanation for potential consumer undervaluation of fuel cost savings." Hypotheses include:

- Consumers might lack the information necessary to estimate the value of future fuel savings, not have a full understanding of this information even when it is presented, or not trust the presented information
- Consumers might be “myopic” and hence undervalue future fuel savings in their purchasing decisions
- Consumers may be accounting for uncertainty in future fuel savings when comparing upfront cost to future returns
- Consumers may consider fuel economy after other vehicle attributes and, as such, not optimize the level of this attribute (instead “satisficing” – that is, selecting a vehicle that is acceptable rather than optimal -- or selecting vehicles that have some sufficient amount of fuel economy)
- Consumers might be especially averse to the short-term losses associated with the higher prices of energy efficient products relative to the long-term gains of future fuel savings (the behavioral phenomenon of “loss aversion”)
- Consumers might associate higher fuel economy with inexpensive, less well designed vehicles
- When buying vehicles, consumers may focus on visible attributes that convey status, such as size, and pay less attention to attributes such as fuel economy that typically do not visibly convey status
- Even if consumers have relevant knowledge, selecting a vehicle is a highly complex undertaking, involving many vehicle characteristics. In the face of such a complicated choice, consumers may use simplified decision rules
- Because consumers differ in how much they drive, they may already sort themselves into vehicles with different, but individually appropriate, levels of fuel economy in ways that an analysis based on an average driver does not identify

EPA has explored the evidence on how consumers evaluate fuel economy in their vehicle purchase decisions.[15] Some research finds that vehicle buyers consider close to all fuel consumption over a vehicle's lifetime in the purchase decision.[16] Others find that vehicle buyers consider only a small share of that future consumption in the purchase decision.[17] Sallee (2014) argues that it might be rational for consumers not to expend too much effort to calculate fuel savings, because increased precision might not have much effect on their purchase decisions.[18] The variation in estimates of willingness to pay is very large, even after outliers are removed; Greene et al. (2018) estimated a mean willingness to pay for a $0.01 reduction in fuel cost per mile among published estimates of $1880, a median of $990, and a standard deviation of $6880, compared to a reference value of $1150 for the value of reducing fuel costs by $0.01/mile over the lifetime of an average vehicle.[a] The estimates vary based on the type of study (revealed preference, stated preference, or market sales), and the form of statistical model used to analyze the data. These observations provide little guidance on whether consumers overvalue or undervalue fuel economy, or get the estimates approximately right. Thus, it is not clear whether consumer behavior is responsible for the energy efficiency gap, much less which hypotheses might explain it.

For possible explanations on the producer side, two major themes arise: the role of market structure and business strategy, and the nature of technological invention and innovation.

- Light-duty vehicle production involves significant fixed costs, and automakers strive to differentiate their products from each other. These observations suggest that automakers can act strategically in how they design and market products. In this context, the fuel economy of a vehicle can become a factor in product differentiation rather than a decision based solely on cost-effectiveness of a fuel-saving technology.[19] Product differentiation carves out corners of the market for different automobile brands and models. For instance, automakers may emphasize luxury characteristics in some vehicles to attract people with preferences for those characteristics, and they may emphasize cost and fuel economy for people attracted to frugality. By separating products into different market segments, producers both provide consumers with goods targeted for their tastes, and may reduce competition among vehicle models, creating the possibility of greater profits. From the producer perspective, fuel economy is not necessarily closely related to the cost-effectiveness of the technologies to consumers, but rather is one of many factors that manufacturers use to market their models to different consumer groups. As Fischer (2005) points out, this strategy can lead to inefficiencies in the market: an under-supply of fuel economy relative to what is cost-effective to consumers in some segments, and an over-supply of fuel economy in other sectors.[20] The structure of the automobile industry may inefficiently allocate car attributes--fuel economy among them--and help to explain the existence of an energy efficiency gap.
- Innovation – the first commercialization of a new product – occurs on a continuum between two extremes: “major” innovation where product characteristics change, and “incremental” innovation[b] which exploits relatively minor changes to the existing product.[21] In the absence of standards, automakers have seemed willing to invest in small improvements upon existing technologies (“incremental” technologies) that can be used to improve fuel economy or other vehicle attributes (Helfand and Dorsey-Palmateer 2015). However, they may be more hesitant to invest in “major” innovations in the absence of standards, for several reasons, including being the first (or one of the first) to invest in a new technology.

[a] It also provides a reference value of $1150 for the value of reducing fuel costs by $0.01/mile over the lifetime of an average vehicle.

[b] Abernathy and Utterback use "major" and "incremental" Henderson and Clark, with a two-dimensional framework, use "radical" and "incremental."

- There may be first-mover disadvantages to investing in new technologies. Many manufacturers prefer to observe the market and follow other manufacturers rather than be the first to market with a specific technology. The “first-mover disadvantage” has been recognized in other research where the “first-mover” pays a higher proportion of the costs of developing technology, but loses the long-term advantage when other businesses follow quickly.[22] This effect may be even more significant when the benefits of new technologies provide public goods: because the general public benefits more from public goods than does the individual producer, producers do not receive appropriate incentives to provide those technologies.
- There could be “dynamic increasing returns” to adopting new technologies, wherein the value of a new technology may depend on how many other companies have adopted the technology -- for instance, creating multiple suppliers for a technology should increase competition, improve quality, and reduce price. This could be due to network effects or learning-by-doing. In a network effects situation, the usefulness of the technology depends on others' adoption of the technology: e.g., a telephone is only useful if other people also have telephones. Learning by doing is the concept that the costs (benefits) of using a particular technology decrease (increase) with use. Both of these incentivize firms to pursue a “wait and see” strategy when it comes to adopting new technologies.[23]
- There can be synergies when companies work on the same technologies at the same time.[24] Research among multiple parties can be a synergistic process: ideas by one researcher may stimulate new ideas by others, and more and better results occur than if the one researcher operated in isolation.[c] Standards can promote research into low-CO_2 technologies that would not take place in the absence of the standards. Because all companies (both auto firms and auto suppliers) have incentives to find better, less expensive ways of meeting the standards, the possibilities for synergistic interactions may increase. Thus, the standards, by focusing all companies on finding more efficient ways of achieving the standards, may lead to better outcomes than if any one company operated on its own.

Much less research has been conducted to evaluate the producer side of the market. The 2015 NAS report (cited in the 2021 NAS report) observes that automakers "perceive that typical consumers would pay upfront for only one to four years of fuel savings" (p. 9-10),[25] a range of values within that identified in Greene et al. (2018) for consumer response, but well below the median or mean. It may be possible, though puzzling, that automakers operate under a misperception of consumer willingness to pay for additional fuel economy. The 2021 NAS Report (p. 11-356) observes that the auto industry is concentrated, "in part owing to the large capital investments necessary to enter the automotive market," and raises the "first-mover disadvantage" argument. In addition, it discusses the challenges associated with a "disruptive" technology such as the transition to electrification (p. 11-358). Thus, it supports the concept that

[c] Powell and Giannella (2010) discuss how a “collective momentum” has led uncoordinated research efforts among a diverse set of players to develop advances in a number of technologies (such as electricity and telephones). They contrast this view of technological innovation with that of proprietary research in corporate laboratories, where the research is part of a corporate strategy. Such momentum may result in part from alignment of economic, social, political, and other goals.

there potentially are barriers to adoption of new technologies on the part of automakers, though it also does not provide conclusive evidence.

Some theories involve the interaction between producers and consumers. For instance,

- "Split incentives" refers to a situation where a person authorized to make a decision for someone else -- an agent -- may have different objectives than the person who will live with the decision -- the principal. For instance, the purchasing agent for a fleet may focus on minimizing purchase costs, in order to buy as many vehicles as possible, though such practice may lead to higher operating and maintenance costs for the fleet managers. This effect may also appear within auto makers, if those influencing the fuel economy of new vehicles have reason to be more focused on up-front costs than in the total cost of ownership that vehicle buyers will face. Split incentives might lead to under-provision of charging facilities for rental properties and workplaces.

In sum, it continues to be an open question which combination of theories may best explain why there was limited adoption of cost-effective fuel-saving technologies before the implementation of more stringent standards, that were adopted without serious disruption to the vehicle market after the standards became effective. Nevertheless, it appears to have happened. Some combination of market failures must explain why markets have not provided all fuel-saving technologies that would save money. Regulation appears to help correct such market failures, while also addressing other externalities like pollution.

8.1.2 How Sales Impacts were Modeled

As discussed in Chapter 4, EPA is using the CAFE Compliance and Effects Modeling System (CCEMS) model for this analysis. The FRIA for the SAFE rule (starting p. 871) describes the approach to vehicle sales impacts used in the model. First, it projects future new vehicle sales in the reference case based on projections of macroeconomic variables. Second, it applies a demand elasticity (that is, the percent change in the quantity sold resulting from a one percent increase in price) to the change in net price, where net price is the difference in technology costs less an estimate of the change in fuel costs over 2.5 years. This approach assumes that vehicle buyers and automakers take into consideration the fuel savings that consumers expect to accrue over the first 2.5 years of vehicle ownership -- an assumption that warrants further evaluation as discussed below. This assumption applies to both the without-program and with-program calculations. It does not allow for different perceptions of the value of fuel economy to buyers on the part of automakers, in providing fuel-saving technologies, and those buyers.

As discussed in Chapter 8.1, there does not yet appear to be consensus around the role of fuel consumption in people's vehicle purchase decisions, and the assumption that 2.5 years of fuel consumption is the right number deserves further evaluation. As noted there, this assumption is consistent with automakers' statements of their perceptions of consumer behavior. Also as noted there, Greene et al. (2018) provides a reference value of $1,150 for the value of reducing fuel costs by $0.01/mile over the lifetime of an average vehicle; for comparison, 2.5 years of fuel savings is about 30 percent of that value, or about $333.[d] This value is within the large standard deviation in Greene et al. (2018) for the willingness to pay to reduce fuel costs, but it is lower than both the mean of $1,880 (160 percent of the reference value) and the median of $990 (85 percent of the reference value) per one cent per mile in the paper. EPA estimates that the present value of 85 percent of fuel consumption is about 10 years of fuel consumption, using Greene et al.'s assumptions.[e] It appears possible that automakers may operate under a different perception of consumer willingness to pay for additional fuel economy than how consumers actually behave. CCEMS does not allow automaker perception to differ from consumer behavior.

In the NPRM, EPA used an elasticity of demand at -1 as its central case, and an elasticity of -0.4 for sensitivity analysis. The value of -1 was based on literature more than 25 years old, and was based on studies that focus on the short run, a period typically considered to be less than one year.[26] For durable goods, such as vehicles, people are expected to have more flexibility about *when* they purchase new vehicles than *whether* they purchase new vehicles; thus, their behavior is more inflexible (less elastic) in the long run than in the short run. For this reason, estimates for long-term elasticities for durable goods are expected to be smaller (in absolute value) than short-run elasticities. At a market level, short-run responses typically focus entirely on the new-vehicle market; longer time spans allow for adjustments between the new and used vehicle markets, and even adjustments outside those markets, such as with public transit. Because this rule has effects over time, and could have effects related to the used vehicle market, long-run elasticities that account for effects in the used vehicle market are more appropriate for estimating the impacts of standards in the new vehicle market than short-run elasticities.

EPA commissioned work with RTI International and its subject matter expert, Dr. Mark Jacobsen of the University of California at San Diego, to review more recent estimates of the elasticity of demand for new vehicles.[27] RTI found that all but one study of short-run elasticities since 1997 have estimated elasticities to be between -0.37 and -0.78; in addition, two studies that account for changes in the used vehicle market provide estimates of -0.18 and -0.36. The RTI report also developed an approach based on economic principles to estimate how changes in the new vehicle market relate to the used vehicle market. Using available parameters from published research, RTI calculated that the "policy elasticity," the value that takes into account effects in the used vehicle market, is much smaller than the short-run demand elasticity. Table 8-1 presents its calculations of the effects of multiple combinations of key parameters and mostly finds elasticity values between -0.14 and -0.27; the one exception, -0.39, is based on the high (in absolute value) new-vehicle demand elasticity of -1.27 and a high estimate for substitution out of the auto market. Thus, this new research suggests that a new-vehicle demand elasticity

[d] Greene et al. (2018) does not provide enough detail to replicate their analysis perfectly. The 30 percent estimate is calculated by assuming, following assumptions in Greene et al. (2018), that a vehicle is driven 15,000 miles per year for 13.5 years, 10 percent discount rate. Those figures produce a "present value of miles" of 108,600; thus, a $0.01/mile change in the cost of driving would be worth $1086. In contrast, saving $0.01/mile for 2.5 years is worth about $318, or 29 percent of the value over 13.5 years. Here we use 29 percent of Greene et al.'s estimate ($1150*0.29 = $333).

[e] With a 10 percent discount rate, the present value of 15,000 miles per year at age 10 is 85 percent of the present value of 15,000 miles per year at age 13.5. For comparison, a 5 percent discount rate achieves 85 percent of the 13.5 years of present value at roughly age 11.

appropriate for these standards -- one that recognizes effects in the used vehicle market -- is between -0.14 and -0.39, and most likely between -0.14 and -0.3.

Table 8-1: Policy Elasticities Corresponding to Selected Demand and Scrappage Elasticities.

	Scenario				Effect of 1% Increase in Generalized Cost of New Vehicles			
	Vehicle Demand Elasticities				Quantities (% changes)			
	New-Vehicle Demand	Cross-Price New/Used	Outside Option	Scrappage Elasticity	New (Policy)	Used	All	Average age
A	−0.40	0.03	0	−0.70	*−0.14*	0.01	0.00	0.09
B	−0.40	0.03	−0.05	−0.70	*−0.17*	−0.04	−0.05	0.08
C	−0.40	0.03	−0.14	−0.70	*−0.23*	−0.10	−0.11	0.08
D	−0.80	0.05	−0.05	−0.70	*−0.25*	−0.04	−0.05	0.15
E	−1.27	0.09	−0.14	−0.70	*−0.39*	−0.12	−0.14	0.21
F	−0.40	0.03	−0.05	−0.20	*−0.14*	−0.06	−0.06	0.07
G	−0.40	0.03	−0.05	−1.20	*−0.19*	−0.03	−0.04	0.08
H	−0.80	0.05	−0.05	−0.20	*−0.19*	−0.07	−0.08	0.12
I	−0.80	0.05	−0.05	−1.20	*−0.27*	−0.03	−0.04	0.15

Note: The policy elasticities, italicized, are the effects in the new vehicle market, taking into account interactions with the used vehicle market and scrappage
This table is Table 7-2 from U.S. Environmental Protection Agency (2021), "The Effects of New-Vehicle Price Changes on New- and Used-Vehicle Markets and Scrappage," EPA-420-R-21-019,

A report submitted in comments from the New York University Institute for Policy Integrity[28] as well as comments provided by the Center for Biological Diversity et al.[29] summarize studies by whether they are short-run or long-run, and when they were conducted. These assessments also point to using a smaller elasticity (in absolute value) than even the -0.4 used as a sensitivity case in the NPRM.

The elasticity does not affect whether the sales are projected to increase or decrease, but it does affect the magnitude of those increases: a 1 percent change in sales for a 1 percent change in net price is a larger effect than a 0.4 percent change for a 1 percent change in net price. Based on the RTI review and analysis, as well as summaries of the literature provided by commenters, there appears to be agreement that newer estimates that account for long-term adjustments indicate an elasticity much smaller (in absolute value) than -1, and likely smaller than -0.4. For this final rule, EPA is using as its primary estimate for the new-vehicle demand elasticity a value of -0.4, to facilitate comparison with the NPRM. We recognize that these assessments point to a more inelastic value than even -0.4, such that a value of -0.4 leads to conservatively large estimates of sales effect, and thus we also conduct a sensitivity analysis of -0.15, to encompass what appears to be the plausible range. For further comparison with the NPRM, we also include a sensitivity using the NPRM central-case elasticity of -1; as discussed above, though, use of this value does not seem to be supported in recent literature.

CCEMS also makes use of a dynamic fleet share model (FRIA p. 877) that estimates, separately, the shares of passenger cars and light trucks based on vehicle characteristics, and then adjusts them so that the market shares sum to one; see RIA Chapter 4.1.4.3. The model also includes the effects of the standards on vehicle scrappage based on a statistical analysis (FRIA starting p. 926). The model looks for associations between age, change in new vehicle prices, fuel prices, cost per mile of driving, and macroeconomic measures and the scrappage rate, with different equations for cars, SUVs/vans, and pickups. Because the scrappage model was revised from the version in the SAFE proposal due to public comments received, the current version has not been subject to review.[f] EPA's project to review new vehicle demand elasticities is also reviewing the literature on the relationship between new and used vehicle markets and scrappage.

With the exception of the demand elasticity, as discussed above, EPA is maintaining the NPRM assumptions for its modeling.

8.1.3 Sales Impacts

With the modeling assumption, described in Chapter 8.1.2, that vehicle buyers consider 2.5 years of future fuel consumption in the purchase decision and a new-vehicle demand elasticity of -0.4, the sales impacts projected by the model are in Table 8-2. Vehicle sales decrease by roughly 1 percent compared to sales in the baseline SAFE rule.

Table 8-2: Sales Impacts, 2.5 Years of Fuel Savings in Net Price, Demand Elasticity -0.4

Year	SAFE (Pre-existing) Standards	Final Rule	Difference	Percent Change
2022	16,498,879	16,451,086	-47,793	-0.3%
2023	17,272,407	17,193,809	-78,598	-0.5%
2024	17,117,138	17,008,480	-108,658	-0.6%
2025	16,765,071	16,637,174	-127,897	-0.8%
2026	16,338,831	16,182,656	-156,175	-1.0%
2027	15,994,684	15,828,358	-166,326	-1.0%
2028	15,761,125	15,596,046	-165,079	-1.0%
2029	15,610,927	15,463,951	-146,976	-0.9%
2030	15,688,194	15,547,979	-140,215	-0.9%
2031	15,920,720	15,779,435	-141,285	-0.9%
2032	16,163,535	16,025,087	-138,448	-0.9%
2033	16,348,003	16,211,481	-136,522	-0.8%
2034	16,486,793	16,353,057	-133,736	-0.8%
2035	16,501,910	16,371,417	-130,493	-0.8%

Table 8-3 examines the impact of using an elasticity of -0.15 on sales. As expected, the smaller (in absolute value) elasticity produces smaller sales impacts. Sales under both the SAFE (pre-existing) standards and the final standards will be higher with the smaller elasticity.

[f] Details on the changes made to the scrappage model can be found in the SAFE FRIA.

Table 8-3: Sales Impacts, 2.5 Years of Fuel Savings in Net Price, Demand Elasticity -0.15

Year	SAFE (Pre-existing) Standards	Final Rule	Difference	Percent Change
2022	16,528,000	16,519,000	-10,000	-0.1%
2023	17,302,000	17,284,000	-18,000	-0.1%
2024	17,144,000	17,116,000	-28,000	-0.2%
2025	16,794,000	16,755,000	-39,000	-0.2%
2026	16,363,000	16,314,000	-49,000	-0.3%
2027	16,016,000	15,963,000	-53,000	-0.3%
2028	15,781,000	15,728,000	-53,000	-0.3%
2029	15,630,000	15,583,000	-47,000	-0.3%
2030	15,707,000	15,662,000	-45,000	-0.3%
2031	15,939,000	15,894,000	-45,000	-0.3%
2032	16,182,000	16,138,000	-44,000	-0.3%
2033	16,367,000	16,324,000	-44,000	-0.3%
2034	16,506,000	16,463,000	-43,000	-0.3%
2035	16,521,000	16,479,000	-42,000	-0.3%

Finally, Table 8-4 provides estimates using -1 as the demand elasticity, for purposes of continuity with the NPRM. Sales impacts are larger, as expected. As discussed above, this elasticity, and thus results based on it, are not supported by current literature.

Table 8-4: Sales Impacts, 2.5 Years of Fuel Savings in Net Price, Demand Elasticity -1

Year	SAFE (Pre-existing) Standards	Final Rule	Difference	Percent Change
2022	16,387,000	16,323,000	-64,000	-0.4%
2023	17,157,000	17,037,000	-120,000	-0.7%
2024	16,997,000	16,813,000	-184,000	-1.1%
2025	16,631,000	16,373,000	-258,000	-1.6%
2026	16,198,000	15,874,000	-324,000	-2.0%
2027	15,855,000	15,501,000	-354,000	-2.2%
2028	15,630,000	15,279,000	-351,000	-2.2%
2029	15,492,000	15,179,000	-314,000	-2.0%
2030	15,575,000	15,276,000	-299,000	-1.9%
2031	15,807,000	15,506,000	-301,000	-1.9%
2032	16,053,000	15,758,000	-295,000	-1.8%
2033	16,236,000	15,945,000	-291,000	-1.8%
2034	16,377,000	16,092,000	-285,000	-1.7%
2035	16,394,000	16,116,000	-278,000	-1.7%

As discussed above, the use of 2.5 years by consumers for consideration of future fuel consumption is smaller than the mean or median estimates in the Greene et al. (2018) meta-analysis for consumer valuation of fuel savings, though it appears to reflect automakers' perception of that value. In addition, it is possible that automakers and vehicle buyers may differ in their practices relating to consumers' willingness to pay for fuel economy. If automakers underestimate consumers' valuation of fuel economy, then sales may increase relative to the baseline under the standards. EPA will continue to evaluate the sales impacts of the standards, including the assumption on consumer valuation of future fuel savings.

How easily new vehicle buyers will be willing to substitute EVs for ICEVs is a matter of some uncertainty. With up-front costs dropping, the total cost of ownership for EVs is also dropping and becoming more competitive with ICEVs. As shown in Table 4-26, our analysis suggests that EV penetration under these standards is projected to increase from about 7 percent in MY 2023 to about 17 percent in MY 2026. The transition to zero emission vehicles is important for achieving climate goals; in addition, as discussed in Chapter 8.2.3, domestic production of EVs is important for future competitiveness of the U.S. auto industry as other markets also make this transition.

8.2 Employment Impacts

8.2.1 Conceptual Framework

Economic theory of labor demand indicates that employers affected by environmental regulation may increase their demand for some types of labor, decrease demand for other types of labor, or for still other types, not change it at all. A variety of conditions can affect employment impacts of environmental regulation, including baseline labor market conditions and employer and worker characteristics such as industry, region, and skill level.

A growing literature has investigated employment effects of environmental regulation. Morgenstern et al. (2002)[30] decompose the labor consequences in a regulated industry facing increased abatement costs into three separate components. First, there is a demand effect caused by higher production costs raising market prices. Higher prices reduce consumption (and production) reducing demand for labor within the regulated industry. Second, there is a cost effect where, as production costs increase, plants use more of all inputs, including labor, to produce the same level of output. Third, there is a factor-shift effect where post-regulation production technologies may have different labor intensities. These three effects outlined by Morgenstern et al. (2002) provides the theoretical foundation for EPA's analysis of the impacts of the regulation on labor throughout Chapter 8.2.[29]

Additional papers approach employment effects through similar frameworks. Berman and Bui (2001) model two components that drive changes in firm-level labor demand: output effects and substitution effects.[31,g] If regulation causes marginal cost to increase, it will place upward pressure on output prices, leading to a decrease in the quantity demanded, and resulting in a decrease in production that they term the output effect. The substitution effect describes how, holding output constant, regulation affects labor intensity of production. Deschênes describes environmental regulations as requiring additional capital equipment for pollution abatement that does not increase labor productivity.[32] These higher production costs induce regulated firms to reduce output and decrease labor demand (an output effect) while simultaneously shifting away from the use of more expensive capital towards increased labor demand (a substitution effect). At the industry level, labor demand is more likely to be responsive to regulatory costs if: (1) the elasticity of labor demand is high relative to the elasticity of labor supply, and (2) labor costs are a large share of total production costs.[33] Labor demand might also respond to regulation if compliance activities change labor intensity in production.

[g] Berman and Bui (2001) also discuss a third component, the impact of regulation on factor prices, but conclude that this effect is unlikely to be important for large competitive factor markets, such as labor and capital.

To study labor demand impacts empirically, researchers have compared employment levels at facilities subject to an environmental regulation to employment levels at similar facilities not subject to that environmental regulation; some studies find no employment effects, and others find statistically significant, usually small differences. For example, see Berman and Bui, Greenstone (2002), Ferris et al. (2014), Walker (2013), and Curtis (2018, 2020).[34]

Workers affected by changes in labor demand due to regulation may experience a variety of impacts including job gains or involuntary job loss and unemployment. Localized reductions in employment may adversely impact individuals and communities just as localized increases may have positive impacts. Workforce adjustments in response to decreases in labor demand can be costly to firms as well as workers, so employers may choose to adjust their workforce over time through natural attrition or reduced hiring, rather than incur costs associated with job separations (see, for instance, Curtis (2018) and Hafstead and Williams (2018).[35]

In addition to impacts on labor demand in directly regulated industries, impacts on related industries are possible too. Industries operating upstream or downstream from the regulated industries may experience changes in labor demand. For example, as described elsewhere in this RIA, we expect the rule to cause a small decline in extracting, refining, transporting, and storing of petroleum fuels, and a small increase in electricity generation which may have consequences for labor demand in those upstream industries. Or lower per-mile fuel costs could lead to increases in demand for ride-sharing or ride-hailing services and cause increases in demand for drivers in those jobs. Firms producing substitutes or complements to the goods produced by the regulated industry may also experience changes in demand for labor. For example, the expected decline in gas station visits may lead to reduced demand for labor in that sector. The magnitude of these impacts depends on a variety of factors including the labor intensities of the related sectors as well as the nature of the linkages (which can be reflected in measures of elasticity) between them and the regulated firms.

As suggested in this discussion, the overall employment effects of environmental regulation are difficult to estimate. Estimation is difficult due to the multitude of small changes in different sectors related to the regulated industry, and because employment impacts are hard to disentangle from other economic changes and business decisions that affect employment, over time and across regions and industries. If the U.S. economy is at full employment, even a large-scale environmental regulation is unlikely to have a noticeable impact on aggregate net employment.[h] Instead, labor is likely primarily to be reallocated from one productive use to another, and net national employment effects from environmental regulation will be small and transitory (e.g., as workers move from one job to another).[36] However, localized reductions in employment may adversely impact individuals and communities just as localized increases may have positive impacts. If the economy is operating at less than full employment, economic theory does not clearly indicate the direction or magnitude of the net impact of environmental regulation on employment; it could cause either a short-run net increase or short-run net decrease.[37]

Because it is challenging to know the state of the macroeconomy when these standards become effective, and also because of the difficulties of modeling impacts on employment in a

[h] Full employment is a conceptual target for the economy where everyone who wants to work and is available to do so at prevailing wages is actively employed. The unemployment rate at full employment is not zero.

complex national economy, we focus our analysis on the direct impacts in closely affected sectors, as described in the next section.

8.2.2 How Employment Impacts were Modeled

The SAFE FRIA (starting p. 1067) describes the calculation of employment impacts for three sets of affected sectors: automotive dealers, final assembly labor and parts production, and fuel-saving (or GHG-reducing) technology labor. The first two of these (automobile dealers and final assembly) are examples of demand-effect employment, while the third (technology labor) reflects cost-effect employment. For automotive dealers, the model estimates the hours involved in each new vehicle sale. Estimating the labor involved in final assembly used average labor hours per vehicle at a sample of U.S. assembly plants, adjusted by the ratio of vehicle assembly manufacturing employment to employment for total vehicle and equipment manufacturing for new vehicles. Finally, for fuel-saving technology labor, the analysis calculated the average revenue per job-year for automakers, and used the revised revenue estimates for calculation of the change in job-years. As with the NPRM, these estimates are still in use for this final rule.

8.2.3 Employment Impacts

Table 8-5 below provides the results of these calculations, combined for these three sectors. It indicates a very small effect on employment, becoming increasingly positive over time, when using the estimate that both automakers and vehicle buyers take 2.5 years of fuel savings into consideration in the purchase decision. Employment increases by roughly 2.5 percent: even though sales decrease slightly, positive cost effect due to increased technology costs outweighs the negative demand effect due to decreased sales.

Table 8-5: Employment Impacts, Based on Sales Estimates in Table 8-2 (Demand Elasticity -0.4)

Year	SAFE (Pre-existing) Standards	Final Rule	Difference	Percent Difference
2022	1,156,000	1,161,000	6,000	0.5%
2023	1,210,000	1,220,000	10,000	0.8%
2024	1,200,000	1,216,000	16,000	1.3%
2025	1,177,000	1,195,000	18,000	1.5%
2026	1,147,000	1,170,000	23,000	2.0%
2027	1,122,000	1,148,000	26,000	2.3%
2028	1,105,000	1,131,000	26,000	2.4%
2029	1,093,000	1,119,000	25,000	2.3%
2030	1,097,000	1,123,000	26,000	2.3%
2031	1,113,000	1,139,000	26,000	2.3%
2032	1,129,000	1,155,000	26,000	2.3%
2033	1,141,000	1,168,000	27,000	2.3%
2034	1,150,000	1,177,000	27,000	2.3%
2035	1,151,000	1,177,000	26,000	2.3%

Table 8-6 shows the effects of using the sales estimates based on an elasticity of -0.15, as shown in Table 8-3. As with the sales impacts, employment under both the SAFE program and this rule are higher with the smaller (in absolute value) elasticity. The effects on employment due to the standards, with this lower elasticity, are positive in all years, and almost the same as those using the elasticity of -0.4. As with that analysis, the positive cost effect outweighs the negative demand effect across all analyzed years.

Table 8-6: Employment Impacts, Based on Sales Estimates in Table 8-3 (Demand Elasticity -0.15)

Year	SAFE (Pre-existing) Standards	Final Rule	Difference	Percent Difference
2022	1,161,000	1,164,000	4,000	0.3%
2023	1,217,000	1,224,000	7,000	0.6%
2024	1,208,000	1,221,000	13,000	1.1%
2025	1,185,000	1,203,000	18,000	1.5%
2026	1,157,000	1,181,000	24,000	2.1%
2027	1,133,000	1,160,000	27,000	2.4%
2028	1,115,000	1,142,000	27,000	2.4%
2029	1,104,000	1,129,000	25,000	2.3%
2030	1,108,000	1,133,000	25,000	2.3%
2031	1,123,000	1,149,000	26,000	2.3%
2032	1,139,000	1,165,000	26,000	2.3%
2033	1,152,000	1,178,000	26,000	2.2%
2034	1,161,000	1,187,000	26,000	2.2%
2035	1,161,000	1,187,000	25,000	2.2%

Finally, Table 8-7 results using a demand elasticity of -1. The results show impacts ranging from 0 to 0.7 percent. As discussed in the context of vehicle sales analysis, while these estimates are presented for continuity with the NPRM analysis, our current assessment does not support the use of results based on this elasticity.

Table 8-7: Employment Impacts, Based on Sales Estimates in Table 8-4 (Demand Elasticity -1)

Year	SAFE (Pre-existing) Standards	Final Rule	Difference	Percent Difference
2022	1,151,000	1,151,000	0	0.0%
2023	1,207,000	1,208,000	0	0.0%
2024	1,198,000	1,200,000	2,000	0.2%
2025	1,174,000	1,176,000	2,000	0.2%
2026	1,145,000	1,150,000	5,000	0.4%
2027	1,121,000	1,127,000	5,000	0.5%
2028	1,105,000	1,110,000	6,000	0.5%
2029	1,094,000	1,100,000	6,000	0.6%
2030	1,098,000	1,106,000	7,000	0.7%
2031	1,114,000	1,121,000	7,000	0.7%
2032	1,130,000	1,138,000	8,000	0.7%
2033	1,143,000	1,151,000	8,000	0.7%
2034	1,152,000	1,160,000	8,000	0.7%
2035	1,153,000	1,161,000	8,000	0.7%

If automakers underestimate consumers' valuation of fuel economy, as noted in Chapter 8.2.3, then demand-effect employment is likely to be higher, and employment impacts are likely to be more positive.

As mentioned, we are only providing partial estimates of employment impacts in the directly regulated sector, plus the impacts for automotive dealers. These do not include economy-wide labor impacts. As discussed in Chapter 8.2.1, economy-wide impacts on employment are generally driven by broad macroeconomic effects. It also does not reflect employment effects due to impacts on related sectors other than car dealerships (those that are upstream or downstream, or producing substitutes and complements). For example, we have not estimated the impacts of reduced spending on fuel consumption. Those changes may lead to some reductions in employment in gas stations, and some increases in other sectors to which people reallocate those expenditures.

Electrification of the vehicle fleet is likely to affect both the number and the nature of employment in the auto and parts sectors and related sectors, such as providers of charging infrastructure. The kinds of jobs in auto manufacturing are expected to change: for instance, there will be no need for exhaust system assembly for EVs, while wiring will become more complex. The effect on total employment for auto manufacturing is uncertain: some suggest that fewer workers will be needed because BEVs have fewer moving parts,[38] while others estimate that the labor-hours involved in BEVs is almost identical to that for ICE vehicles.[39] Effects in the supply chain, as SAFE and the Alliance noted, depend on where goods in the supply chain are developed. Blue-Green Alliance, BICEP, Ceres, and SAFE all argue that developing EVs in the U.S. is critical for domestic employment and for the global competitiveness of the U.S. in the future auto industry: as other countries are moving rapidly to develop EVs, the U.S. auto industry risks falling behind. EPA will continue to assess changes in employment as electrification of the auto industry proceeds.

8.3 Environmental Justice

Executive Order 12898 (59 FR 7629, February 16, 1994) establishes federal executive policy on environmental justice. It directs federal agencies, to the greatest extent practicable and permitted by law, to make achieving environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States. EPA defines environmental justice as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.[i]

Executive Order 14008 (86 FR 7619, February 1, 2021) also calls on federal agencies to make achieving environmental justice part of their respective missions "by developing programs, policies, and activities to address the disproportionately high and adverse human health, environmental, climate-related and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impacts." It declares a policy "to secure environmental justice and spur economic opportunity for disadvantaged communities that have

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[i] Fair treatment means that "no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental and commercial operations or programs and policies." Meaningful involvement occurs when "1) potentially affected populations have an appropriate opportunity to participate in decisions about a proposed activity [e.g., rulemaking] that will affect their environment and/or health; 2) the public's contribution can influence [the EPA's rulemaking] decision; 3) the concerns of all participants involved will be considered in the decision-making process; and 4) [the EPA will] seek out and facilitate the involvement of those potentially affected" A potential EJ concern is defined as "the actual or potential lack of fair treatment or meaningful involvement of minority populations, low-income populations, tribes, and indigenous peoples in the development, implementation and enforcement of environmental laws, regulations and policies." See "Guidance on Considering Environmental Justice During the Development of an Action." Environmental Protection Agency, www.epa.gov/environmentaljustice/guidanceconsidering-environmental-justice-duringdevelopment-action. See also https://www.epa.gov/environmentaljustice.

been historically marginalized and overburdened by pollution and under-investment in housing, transportation, water and wastewater infrastructure and health care."

Under Executive Order 13563, federal agencies may consider equity, human dignity, fairness, and distributional considerations in their regulatory analyses, where appropriate and permitted by law.

EPA's 2016 "Technical Guidance for Assessing Environmental Justice in Regulatory Analysis" provides recommendations on conducting the highest quality analysis feasible, recognizing that data limitations, time and resource constraints, and analytic challenges will vary by media and regulatory context.[40]

When assessing the potential for disproportionately high and adverse health or environmental impacts of regulatory actions on populations of color, low-income populations, tribes, and/or indigenous peoples, the EPA strives to answer three broad questions: (1) Is there evidence of potential EJ concerns in the baseline (the state of the world absent the regulatory action)? Assessing the baseline will allow the EPA to determine whether pre-existing disparities are associated with the pollutant(s) under consideration (e.g., if the effects of the pollutant(s) are more concentrated in some population groups). (2) Is there evidence of potential EJ concerns for the regulatory option(s) under consideration? Specifically, how are the pollutant(s) and its effects distributed for the regulatory options under consideration? And, (3) do the regulatory option(s) under consideration exacerbate or mitigate EJ concerns relative to the baseline? It is not always possible to quantitatively assess these questions.

EPA's 2016 Technical Guidance does not prescribe or recommend a specific approach or methodology for conducting an environmental justice analysis, though a key consideration is consistency with the assumptions underlying other parts of the regulatory analysis when evaluating the baseline and regulatory options. Where applicable and practicable, the Agency endeavors to conduct such an analysis. Going forward, EPA is committed to conducting environmental justice analysis for rulemakings based on a framework similar to what is outlined in EPA's Technical Guidance, in addition to investigating ways to further weave environmental justice into the fabric of the rulemaking process.

8.3.1 GHG Impacts

In 2009, under the *Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* ("Endangerment Finding"), the Administrator considered how climate change threatens the health and welfare of the U.S. population. As part of that consideration, she also considered risks to minority and low-income individuals and communities, finding that certain parts of the U.S. population may be especially vulnerable based on their characteristics or circumstances. These groups include economically and socially disadvantaged communities; individuals at vulnerable lifestages, such as the elderly, the very young, and pregnant or nursing women; those already in poor health or with comorbidities; the disabled; those experiencing homelessness, mental illness, or substance abuse; and/or Indigenous or minority populations dependent on one or limited resources for subsistence due to factors including but not limited to geography, access, and mobility.

Scientific assessment reports produced over the past decade by the U.S. Global Change Research Program (USGCRP),[41,42] the Intergovernmental Panel on Climate Change

(IPCC),[43,44,45,46] and the National Academies of Science, Engineering, and Medicine[47,48] add more evidence that the impacts of climate change raise potential environmental justice concerns. These reports conclude that poorer or predominantly non-White communities can be especially vulnerable to climate change impacts because they tend to have limited adaptive capacities and are more dependent on climate-sensitive resources such as local water and food supplies, or have less access to social and information resources. Some communities of color, specifically populations defined jointly by ethnic/racial characteristics and geographic location, may be uniquely vulnerable to climate change health impacts in the United States. In particular, the 2016 scientific assessment on the *Impacts of Climate Change on Human Health*[49] found with high confidence that vulnerabilities are place- and time-specific, lifestages and ages are linked to immediate and future health impacts, and social determinants of health are linked to greater extent and severity of climate change-related health impacts.

8.3.1.1 Effects on Specific Populations of Concern

Individuals living in socially and economically disadvantaged communities, such as those living at or below the poverty line or who are experiencing homelessness or social isolation, are at greater risk of health effects from climate change. This is also true with respect to people at vulnerable lifestages, specifically women who are pre- and perinatal, or are nursing; *in utero* fetuses; children at all stages of development; and the elderly. Per the Fourth National Climate Assessment, "Climate change affects human health by altering exposures to heat waves, floods, droughts, and other extreme events; vector-, food- and waterborne infectious diseases; changes in the quality and safety of air, food, and water; and stresses to mental health and well-being."[50] Many health conditions such as cardiopulmonary or respiratory illness and other health impacts are associated with and exacerbated by an increase in greenhouse gases and climate change outcomes, which is problematic as these diseases occur at higher rates within vulnerable communities. Importantly, negative public health outcomes include those that are physical in nature, as well as mental, emotional, social, and economic.

To this end, the scientific assessment literature, including the aforementioned reports, demonstrates that there are myriad ways in which these populations may be affected at the individual and community levels. Individuals face differential exposure to criteria pollutants, in part due to the proximities of highways, trains, factories, and other major sources of pollutant-emitting sources to less-affluent residential areas. Outdoor workers, such as construction or utility crews and agricultural laborers, who frequently are comprised of already at-risk groups, are exposed to poor air quality and extreme temperatures without relief. Furthermore, individuals within EJ populations of concern face greater housing, clean water, and food insecurity and bear disproportionate economic impacts and health burdens associated with climate change effects. They have less or limited access to healthcare and affordable, adequate health or homeowner insurance. Finally, resiliency and adaptation are more difficult for economically disadvantaged communities: They have less liquidity, individually and collectively, to move or to make the types of infrastructure or policy changes to limit or reduce the hazards they face. They frequently are less able to self-advocate for resources that would otherwise aid in building resilience and hazard reduction and mitigation.

The assessment literature cited in EPA's 2009 and 2016 Endangerment Findings, as well as *Impacts of Climate Change on Human Health*,[48] also concluded that certain populations and life stages, including children, are most vulnerable to climate-related health effects. The assessment literature produced from 2016 to the present strengthens these conclusions by providing more detailed findings regarding related vulnerabilities and the projected impacts youth may experience. These assessments – including the Fourth National Climate Assessment (2018) and *The Impacts of Climate Change on Human Health in the United States* (2016) – describe how children's unique physiological and developmental factors contribute to making them particularly vulnerable to climate change. Impacts to children are expected from heat waves, air pollution, infectious and waterborne illnesses, and mental health effects resulting from extreme weather events. In addition, children are among those especially susceptible to allergens, as well as health effects associated with heat waves, storms, and floods. Additional health concerns may arise in low-income households, especially those with children, if climate change reduces food availability and increases prices, leading to food insecurity within households.

The Impacts of Climate Change on Human Health[48] also found that some communities of color, low-income groups, people with limited English proficiency, and certain immigrant groups (especially those who are undocumented) live with many of the factors that contribute to their vulnerability to the health impacts of climate change. While difficult to isolate from related socioeconomic factors, race appears to be an important factor in vulnerability to climate-related stress, with elevated risks for mortality from high temperatures reported for Black or African American individuals compared to White individuals after controlling for factors such as air conditioning use. Moreover, people of color are disproportionately exposed to air pollution based on where they live, and disproportionately vulnerable due to higher baseline prevalence of underlying diseases such as asthma, so climate exacerbations of air pollution are expected to have disproportionate effects on these communities.

Native American Tribal communities possess unique vulnerabilities to climate change, particularly those impacted by degradation of natural and cultural resources within established reservation boundaries and threats to traditional subsistence lifestyles. Tribal communities whose health, economic well-being, and cultural traditions depend upon the natural environment will likely be affected by the degradation of ecosystem goods and services associated with climate change. The IPCC indicates that losses of customs and historical knowledge may cause communities to be less resilient or adaptable.[51] The Fourth National Climate Assessment (2018) noted that while Indigenous peoples are diverse and will be impacted by the climate changes universal to all Americans, there are several ways in which climate change uniquely threatens Indigenous peoples' livelihoods and economies[52]. In addition, there can institutional barriers to their management of water, land, and other natural resources that could impede adaptive measures.

For example, Indigenous agriculture in the Southwest is already being adversely affected by changing patterns of flooding, drought, dust storms, and rising temperatures leading to increased soil erosion, irrigation water demand, and decreased crop quality and herd sizes. The Confederated Tribes of the Umatilla Indian Reservation in the Northwest have identified climate risks to salmon, elk, deer, roots, and huckleberry habitat. Housing and sanitary water supply infrastructure are vulnerable to disruption from extreme precipitation events.

NCA4 noted that Indigenous peoples often have disproportionately higher rates of asthma, cardiovascular disease, Alzheimer's, diabetes, and obesity, which can all contribute to increased vulnerability to climate-driven extreme heat and air pollution events. These factors also may be exacerbated by stressful situations, such as extreme weather events, wildfires, and other circumstances.

NCA4 and IPCC AR5[53] also highlighted several impacts specific to Alaskan Indigenous Peoples. Coastal erosion and permafrost thaw will lead to more coastal erosion, exacerbated risks of winter travel, and damage to buildings, roads, and other infrastructure – these impacts on archaeological sites, structures, and objects that will lead to a loss of cultural heritage for Alaska's Indigenous people. In terms of food security, the NCA discussed reductions in suitable ice conditions for hunting, warmer temperatures impairing the use of traditional ice cellars for food storage, and declining shellfish populations due to warming and acidification. While the NCA also noted that climate change provided more opportunity to hunt from boats later in the fall season or earlier in the spring, the assessment found that the net impact was an overall decrease in food security.

In addition, the U.S. Pacific Islands and the indigenous communities that live there are also uniquely vulnerable to the effects of climate change due to their remote location and geographic isolation. They rely on the land, ocean, and natural resources for their livelihoods, but face challenges in obtaining energy and food supplies that need to be shipped in at high costs. As a result, they face higher energy costs than the rest of the nation and depend on imported fossil fuels for electricity generation and diesel. These challenges exacerbate the climate impacts that the Pacific Islands are experiencing. NCA4 notes that Indigenous peoples of the Pacific are threatened by rising sea levels, diminishing freshwater availability, and negative effects to ecosystem services that threaten these individuals' health and well-being.

8.3.2 Non-GHG Impacts

In addition to significant climate change benefits, the standards will also impact non-GHG emissions. In general, we expect small non-GHG emissions reductions from upstream sources related to refining petroleum fuels. We also expect small increases in emissions from upstream electricity generating units (EGUs). An increase in emissions from coal- and NG-fired electricity generation to meet increased EV electricity demand could result in adverse EJ impacts. For on-road light-duty vehicles, the standards will reduce total non-GHG tailpipe emissions, though we expect small increases in some non-GHG emissions in the years immediately following implementation of this rule, followed by growing decreases in non-GHG emissions in later years. This is due to our projections about the gasoline-fueled LD vehicle population in the final rule scenario, including decreased scrappage of older vehicles. See Chapter 5.1.2 for more detail on the estimated non-GHG emissions impacts of the rule.[j] As discussed in Section I.A.1 of the Preamble Executive Summary, future EPA actions that would result in increased ZEVs and emissions reductions from the power sector would more significantly change the non-GHG impacts of transportation and electricity generation, and those impacts will be analyzed in more detail in those future actions.

There is evidence that communities with EJ concerns could be impacted by the non-GHG emissions from light-duty vehicles.[54] Numerous studies have found that environmental hazards such as air pollution are more prevalent in areas where populations of color and low-income populations represent a higher fraction of the population compared with the general population.[55,56,57] Consistent with this evidence, a recent study found that most anthropogenic sources of $PM_{2.5}$, including industrial sources, and light- and heavy-duty vehicle sources, disproportionately affect people of color.[58]

Analyses of communities in close proximity to upstream sources, such as EGUs, have found that a higher percentage of communities of color and low-income communities live near these sources when compared to national averages.[59] Vulnerable populations near upstream refineries may experience potential disparities in pollution-related health risk from that source.[60] In this rule we expect that small increases in non-GHG emissions from EGUs and small reductions in petroleum-sector emissions would lead to small changes in exposure to these non-GHG pollutants for people living in the communities near these facilities.

There is also substantial evidence that people who live or attend school near major roadways are more likely to be of a non-White race, Hispanic ethnicity, and/or low socioeconomic status.[61,62] We would expect that communities near roads will benefit from reductions of non-GHG pollutants as fuel efficiency improves and the use of ZEVs (such as full battery electric vehicles) increases, though projections about the gasoline-fueled LD vehicle population, including decreased scrappage, may offset some of these emission reductions, especially in the years immediately after finalization of the standards.

Although proximity to an emissions source is a useful indicator of potential exposure, it is important to note that the impacts of emissions from both upstream and tailpipe sources are not limited to communities in close proximity to these sources. The effects of potential increases and decreases in emissions from the sources affected by this rule might also be felt many miles away, including in communities with EJ concerns. The spatial extent of these impacts from upstream and tailpipe sources depend on a range of interacting and complex factors including the amount of pollutant emitted, atmospheric chemistry and meteorology.

In summary, we expect this rule will, over time, result in reductions of non-GHG tailpipe emissions and emissions from upstream refinery sources. We also project that the rule will result in small increases of non-GHG emissions from upstream EGU sources. Overall, there are substantial $PM_{2.5}$-related health benefits associated with the non-GHG emissions reductions that this rule will achieve. The benefits from these emissions reductions, as well as the adverse impacts associated with the emissions increases, could potentially impact communities with EJ concerns, though not necessarily immediately and not equally in all locations. For this rulemaking, the air quality information needed to perform a quantified analysis of the distribution of such impacts was not available. We therefore recommend caution when interpreting these broad, qualitative observations. EPA intends to develop a future rule to control emissions of GHGs, criteria pollutants, and air toxic pollutants from light-duty vehicles for model years beyond 2026. We are considering how to project air quality impacts from the changes in non-GHG emissions for that future rulemaking (see Section V.C of the Preamble) and how to consider potential EJ concerns that may stem from them.

8.4 Affordability and Equity Impacts

Executive Order 13985 defines equity as "the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment, such as Black, Latino, and Indigenous and

Native American persons, Asian Americans and Pacific Islanders and other persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality." In the context of transportation, Guo et al. (2020) consider both horizontal and vertical equity: horizontal equity involves even distribution of resources in the population, while vertical or social equity "aims to provide services to those who need them most."[63] These definitions suggest that equity involves reducing disparities in both resources and access across income and demographic groups.

While a full assessment of the effects of these standards on equity is not available, those impacts depend in part on their effects on the affordability of vehicles and impacts on lower-income households.

Access to transportation improves the ability of people, including those with low income, to pursue jobs, education, health care, and necessities of daily life such as food and housing. These standards might affect affordability of vehicles and their impacts on low-income households in particular. We acknowledge that vehicles, especially household vehicle ownership, are only a portion of the larger issue of access to transportation and mobility services, which also takes into consideration public transportation and urban design. In addition, online working and shopping may provide alternative ways to accomplish some goals, for those with stable access to internet services. Though these issues are inextricably linked, the following discussion focuses on effects related to private vehicle ownership and use. We also acknowledge that the emissions of vehicles, both local pollutants and greenhouse gases, can have disproportionate impacts on lower-income and minority communities; see Chapter 8.3 and Preamble Section VII.L. for further discussion of these topics.

The SAFE rule discussed affordability primarily as relating to the up-front purchase price of a new vehicle: if the up-front price increased, due to addition of fuel-saving technologies, then vehicles became less affordable. E.g., "technologies added to comply with fuel economy standards have an impact on vehicle prices, and, by extension, on the affordability of newer, safer vehicles, and therefore on the rates at which newer vehicles are acquired and older, less safe vehicles are retired from use" (85 FR 24742). While this is one use of the concept of affordability, it is not the only one.

Hutchens et al. (2021)[64] and the TSD for the MTE Proposed Determination,[65] Chapter 4.3.1, discuss the lack of specificity in the concept of affordability in academic literature. For instance, Bradley (2008)[66] identified affordability as “a vague concept…When pundits use the word 'afford,' there is no clear definition of affordability; it is at best a subjective notion.” Bartl (2010)[67] declared that “affordability is a new ‘alien’ concept penetrating the field of contract and consumer law.” Researchers have nevertheless grappled with attempting to define the term for goods including energy, food, telephone service, health insurance, and housing. Some themes that appear in the different definitions of affordability include:

- Instead of focusing on the traditional economic concept of willingness to pay, any consideration of affordability must also consider the ability to pay for a socially defined minimum level of a good, especially of a necessity.
- Although the ability to pay is often based on the proportion of income devoted to expenditures on a particular good, this ratio approach is widely criticized for not

considering expenditures on other possibly necessary goods, for not considering quality differences in the good, and for not considering heterogeneity of consumer preferences for the good.

- Assessing affordability should take into account both the short-term costs and long-term costs associated with consumption of a particular good.

These themes were all developed in the context of goods typically deemed essential, such as food and housing. There is very little literature applying the concept of affordability to transportation, much less to vehicle ownership. Thakuriah and Liao (2006)[68] attempted to define ability to pay for transportation expenditures, but do not offer a definition of affordable transportation. A report by the Manhattan Strategy Group for the Department of Transportation and the Department of Housing and Urban Development (HUD) (Schanzenbach and McGranahan, 2012)[69] attempted to create metrics of various types of vehicle costs to be included in HUD's Location Affordability Index, which considers housing and transportation costs based on location. However, this report also did not attempt to define vehicle affordability.

It is not clear how to identify the socially acceptable minimum level of transportation service. It seems reasonable to assume that such a socially acceptable minimum level should allow access to employment, education, and basic services like buying food, but it is not clear where consumption of transportation moves from necessity to optional. Normatively defining the minimum adequate level of transportation consumption is difficult given the heterogeneity of consumer preferences and living situations. As a result, it is challenging to define how much residual income should remain with each household after transportation expenditures. It is therefore not surprising that academic and policy literature have largely avoided attempting to define transportation affordability.

We do not here offer a quantitative measure of the affordability of new vehicles. Instead, as in the NPRM, we follow the approach in the Proposed Determination for the Midterm Evaluation[70] of considering four questions that relate to the effects of the LDV GHG standards on new vehicle affordability and equity: how the standards affect low-income households; how the standards affect the used vehicle market; how the standards affect access to credit; and how the standards affect the low-priced vehicle segment. These questions are intended to examine some ways in which the standards might influence the distribution of access to transportation across the public, especially those who might disproportionately suffer from low access.

8.4.1 Effects on Lower-Income Households

As noted in Chapter 8.4, there is no commonly accepted definition of affordable access to transportation. Access to transportation involves access to any form of transportation, not only vehicle ownership and access, but also public transportation, ride-sharing, and ride-hailing services. Within vehicle ownership, access does not involve only the up-front costs of purchasing a vehicle, but also the operating and maintenance costs of a vehicle. Trying to define a socially acceptable minimum level for access to transportation services is even more difficult, because such requirements will vary with geography and personal needs. People in rural areas are unlikely to be able to rely on public transit, for instance. Though nutritious food is a generally acknowledged necessity, people who live in urban food deserts may suffer in health and quality of life due to the transportation time and cost of accessing adequate and nutritious food. On the other hand, those who live in areas with good, inexpensive public transportation and easy access to stores and other desired destinations may be able to rely on public transportation, bicycling, or walking to meet their needs, and not need a personally owned vehicle. How the standards might affect affordable access to transportation is thus a complex question.

A first point to note is that the standards on average are projected to have fuel savings over the lifetime of the vehicles that exceed the up-front costs (see Chapter 6 and Preamble Section VII.J). Thus, on average, the standards are expected to reduce the total cost of ownership of new vehicles subject to the standards. This metric on its own implies that vehicle affordability is enhanced by the standards. This metric is nevertheless likely to be overly simplistic for the purposes of understanding the distributional effects of the standards on equitable access to transportation, and specifically the effects on lower-income households. It does not measure, for instance, who is likely to get the benefits of the fuel savings, and who bears the increased up-front costs of the vehicle. If those groups are different, then it is not initially obvious who earns the net benefits.

It should also be noted that low-income households, defined as households having annual after-tax income below the current-year's median after-tax income level, are much more likely to have used vehicles than new ones. For instance, 70 percent of new vehicle buyers have income above $75,000;[71] median household income in 2019 was about $68,700.[72] Thus, lower-income households will eventually feel the effects of reduced fuel consumption in new vehicles over time, when those vehicles are resold on the used market. Lower-income households are also more likely to experience the effects of price changes in the used vehicle market as explained in Chapter 8.4.2, below. As discussed in Preamble Section VII.J., purchasers of used vehicles subject to these standards are likely to experience greater net gains than the purchasers of new vehicles, because the up-front cost of a vehicle depreciates much more rapidly than do the fuel savings.

A few recent papers have asked whether fuel economy standards are progressive or regressive -- that is, having greater beneficial effects or more adverse effect on lower-income households than on higher-income households. Jacobsen (2013)[73] finds, for the flat (not footprint-based) standard used in the CAFE program before MY 2011, the standards were regressive by implicitly discouraging more desired larger vehicles. The subsequent use of the footprint-based standard is intended to reduce the disincentives for larger vehicles. Levinson (2019)[74] as well as Davis and Knittel (2019),[75] on the other hand, criticize the use of footprint-based standards for not providing incentives for people to buy smaller vehicles. These papers argue that the standards are more harmful to lower-income households than a gasoline tax would be, in part because a gasoline tax is more economically efficient, in part because higher-income households can better afford the up-front cost increase, and in part because the revenues from a gasoline tax can be redistributed in ways to reduce (or eliminate) the regressivity of the tax. Neither of these papers addresses the reduction in fuel costs associated with the standards, though, and thus they omit a significant effect of the standards.

The focus on vehicle ownership does not account for how the standards' effects on reduction in per-mile costs might affect access to transportation for lower-income households. If these reductions in operating costs are passed along to users, ride-hailing and ride-sharing services might become less expensive and thus more accessible than before. Vehicles used in these services are likely to have higher mileage more quickly than personally owned vehicles; as a result, up-front costs are likely to be recovered more quickly than the costs for personally owned vehicles.

Greene and Welch (2018)[76] include both fuel consumption and up-front costs in the calculation of distributional effects. They find that higher-income households experience decreases in fuel consumption due to the standards before lower-income households, because the latter are more likely to own used vehicles and thus get the fuel savings with a lag. However, they estimate that the ratio of fuel savings to costs, as well as the ratio of net savings to income, is higher for lower-income households than higher-income households.

Vaidyanathan et al. (2021) observe that gasoline burden — the share of gasoline in income — is more than three times higher for lower-income households than higher-income households.[77] Thus, reducing per-mile costs may disproportionately benefit lower-income households, both through more efficient vehicles gradually entering the used vehicle fleet, as well as through reduced operating costs for other providers of transportation services. In addition, lower-income households spent more per year on used vehicles than new ones. As discussed in Preamble Section VII.J., because used vehicles have lower up-front costs (due to vehicle depreciation) but still achieve the same reduced fuel consumption of the vehicle when it was new, buyers of used vehicles will recover up-front costs much more quickly than new vehicle buyers. Expenditures on fuel also fluctuate more than expenditures on vehicles, suggesting more uncertainty for fuel costs.

Battery electric vehicles at this time have even higher new-vehicle costs and even lower operating and maintenance costs than ICEVs. The advent of increased market penetration of BEVs on lower-income households depends heavily both on how the new vehicle market responds to those two factors, and on the availability of charging infrastructure for those households. If EVs prove popular with new vehicle buyers, then the used vehicle market for EVs will have increased availability; if EVs are slow to enter the new vehicle market, then the used vehicle market will remain primarily ICEVs. In addition, the cost per mile of ride-sharing and ride-hailing services are likely to depend on the penetration of EVs into those fleets. With their higher use than personally owned vehicles, fleet vehicles may get up-front costs paid back more quickly via reduced operating costs and may be expected to pass some of the reduced operating costs to customers. Depending on the availability and cost of these services, lower-income households without vehicles may have increased access to transportation. Challenges arise with the availability of charging infrastructure for lower-income households: home charging, for instance, may not be feasible if multi-unit dwellings do not offer charging or do not offer sufficient charging access, or if people rely on-street parking. The availability of local, publicly available charging infrastructure may thus influence the decision on whether to purchase an EV. As a result, the penetration of EVs into lower-income neighborhoods may depend on public and private decisions over where to place charging infrastructure.

In sum, the effects of the standards on low-income households are likely to be felt primarily through effects on operating costs, and the effects of the standards on the used vehicle market. While the standards are projected to reduce per-mile operating costs, and thus potentially increase access to mobility, increases in new vehicle costs are likely to affect the used vehicle market as well. This is discussed in Chapter 8.4.2.

8.4.2 Effects on the Used Vehicle Market

Most people in the market for a vehicle purchase used vehicles: according to the U.S. Bureau of Transportation Statistics, roughly two-thirds of vehicles sold in recent years have been used rather than new.[78] Further, according to Consumer Federation of America, in 2015 about 92 percent of vehicle purchases by low-income households were used vehicles.[79] Thus, the effects of the standards on many households depend on its impacts, not only in the new vehicle market, but also in the used vehicle market.

Vehicles are long-lived, durable goods. The vehicles purchased this year are likely to last for several decades, and their characteristics, including their fuel consumption, will mostly persist for that time. As discussed in Preamble Section VII.J., recovery of the increase in up-front costs of a used vehicle by reduced fuel expenditures happens much more rapidly than for a new vehicle, because the up-front costs are depreciated.

The effect of the standards on the used vehicle market will be related to the effects of the standards on new vehicle prices, the fuel efficiency of new vehicle models, the fuel efficiency of used vehicles, and the total sales of new vehicles. On one hand, if the consumer value of fuel savings resulting from improved fuel efficiency outweighs the average increase in new models' prices to potential buyers of new vehicles, sales of new vehicles could rise, and the used vehicle market may increase in volume as new vehicle buyers sell their older vehicles. If this is the case, lower-income households are likely to benefit from the increased availability of used vehicles. On the other hand, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles could decline, and the used vehicle market may decrease in volume as people hold onto their vehicles longer. In this case, lower-income households could face increased costs due to reduced availability of used vehicles.

As discussed in Chapter 8.1.2, EPA contracted with RTI International to understand better the connections between the new and the used vehicle market.[80] Changes in the new vehicle market are expected not only to have immediate effects on the prices of used vehicles, but also to affect the market over time, as the supply of used vehicles in the future depends on how many new vehicles are sold. As described in that subchapter, considering the interaction with the used vehicle market leads to a less elastic demand elasticity for new vehicles. This result arises because, as the price of used vehicles increases, new vehicle buyers are likely to notice that they may recoup some of the new-vehicle price increase when they sell the vehicle as used. Thus, buyers are less discouraged from buying new vehicles than if they did not recognize effects in the used vehicle market. Using a range of parameters from published literature for sensitivity analyses, this report estimates in Tables 8-2 and 8-3 that a 1 percent increase in new vehicle net price would increase the price of a 5-year-old vehicle by between 1 and 1.4 percent, and would reduce overall vehicle stock by 0.04 to 0.11 percent. That is, changes in new vehicle prices are not expected to have a very large effect on the total stock of vehicles.

If the only effect of the standards on total cost of ownership were the up-front costs, then the standards might also encourage people to hold onto their used vehicles longer. This effect, sometimes termed the "Gruenspecht effect" after Gruenspecht (1982),[81] would lead to both slower adoption of vehicles subject to the new standards, and more use of older vehicles not subject to the new standards, with associated higher emissions. Two older studies examine the effects of new vehicle prices on scrappage: Miaou (1995)[82] estimates an elasticity of -0.2 (that is, a 1 percent increase in new vehicle price leads to a 0.2 percent decrease in scrappage), while Greenspan and Cohen (1999)[83] estimate an elasticity of -0.8. Two newer studies estimate the effects of changes in used vehicle prices on scrappage; Jacobsen and van Benthem (2015)[84] estimate an elasticity of -0.7, and Bento et al. (2018)[85] estimate an elasticity of -0.4. These estimates suggest that scrappage rates are likely to change a relatively small amount in response to changes in the new vehicle market.

The NAS 2021 Report[86] (p. 11-357) notes the possibility of the Gruenspecht effect on scrappage. In addition, it notes that, if people find the reduced fuel consumption of new vehicles attractive, new vehicle sales would increase, and reduced scrappage would not be expected.

8.4.3 Effects on Access to Credit

Another question is whether higher vehicle prices may exclude some prospective consumers from the new vehicle market through effects on consumers' ability to finance vehicles. It is possible that lenders focus solely on the amount of the vehicle loan, the person's current debt, and the person's income when issuing loans, and not the costs associated with fuel consumption. If lenders restrict consideration to the amount of the loan, the borrower's debt, and the borrower's income, then increased up-front costs of new vehicles subject to the standards will reduce buyers' ability to get loans. However, if fuel savings are factored into lenders' decisions, reduced fuel costs increase a borrower's capacity to repay a loan and therefore increase the likelihood of getting a loan. Ignoring fuel savings could prevent a buyer's ability to get a loan, even if fuel savings exceed the increase in loan payments due to higher purchase price. Thus, if lenders do not take fuel savings into account in providing loans, households that are borrowing near the limit of their abilities to borrow will either have to buy a different vehicle than intended, or not buy a vehicle at all.

On the other hand, some lenders give discounts for loans to purchase more fuel-efficient vehicles.[87] The National Automobile Dealers Association in its comments provided results of two surveys of financial institutions, which were asked whether they would increase credit for a more expensive vehicle with lower cost of ownership. With about half of those surveyed responding, over 80 percent of respondents replied that they would not; the remainder said they would. These findings do not contradict EPA's finding that some lenders are willing to give discounts on loans to purchase more fuel-efficient vehicles. In addition, subsidies exist from the federal government, and some state governments, for plug-in electric vehicles.[88] When automakers comply with the standards through production of plug-in vehicles, these subsidies reduce the costs of these vehicles and facilitate their purchases. Concerns have been raised that these subsides go primarily to wealthier households, who are more likely to purchase new vehicles in general and may be an expensive way to promote adoption of these vehicles. Sheldon and Dua (2019)[89] find that subsidies targeted by income and other factors may be more cost-effective and progressive financially than untargeted policies.

Hutchens et al. (2021) examined the question whether the higher up-front cost might create an obstacle if borrowers face a ceiling on the debt-to-income ratio (DTI), which affects a borrower's access to credit. Evidence previously suggested that lenders may not give loans to consumers who have a DTI above 36 percent; more recent evidence suggests that lenders consider 43 percent the maximum.[90] Hutchens et al., using data from the U.S. Bureau of Labor Statistics' Consumer Expenditure Survey, found that, from 2007 to 2019, 40 percent of lower-income households and 8 percent of higher-income households both had a DTI of over 36 percent and purchased at least one new vehicle. The 36 percent threshold was maintained for continuity with previous research. In 2019, 59 percent of lower-income households that purchased either a new or used vehicle with a DTI of over 36 percent financed their car purchases. Thus, a DTI above 36 percent may not always be a disqualifying threshold in financing a new vehicle

It is worth mentioning that in addition to the factors discussed here, there are other factors that may influence access to credit, such as race, ethnicity, gender, gender identity, residential location, religion, or other factors. It is unclear whether or to what extent these possible limitations on access to credit may affect access to auto loans.

Although access to credit is a potential barrier to purchase of vehicles whose up-front costs increase, it may be a less impenetrable barrier when those up-front costs come with reduced fuel consumption.

8.4.4 Effects on Low-Priced Cars

Average transaction price for a new vehicle in February 2021 was $41,000, an increase of 6.5 percent from February 2020. That increase, though, masks great diversity in vehicle prices; for instance, the average transaction price for subcompacts at the same time was $18,300.[91] For that reason, low-priced vehicles may be considered an entry point for people into buying new vehicles instead of used ones; automakers may seek to entice people to buy new vehicles through a low price point. It is possible that higher costs associated with the standards could affect the ability of automakers to maintain vehicles in this segment.

In the past, when CAFE standards did not vary by footprint, not only was the low-priced vehicle segment a way to encourage first-time new vehicle purchasers, but it also tended to include more fuel-efficient vehicles that assisted automakers in achieving CAFE standards.[92] The footprint-based standards, by encouraging improvements in GHG emissions and fuel economy across the vehicle fleet, reduce the need for smaller, and by extension, low-priced vehicles to be a primary means of compliance with the standards. This change in incentives for the marketing of this segment may contribute to the increases in the prices of vehicles previously in this category. Hutchens et al. (2021) found that, from 2005-2019, the number of vehicles priced below $20,000 (2019$) has varied from 48 to 66, with 49 such vehicles available in 2019. Both MotorTrend[93] and Car and Driver[94] provide a list of the ten least expensive new vehicles for MY 2021. The lowest priced, the Chevrolet Spark, is listed at under $15,000. Car and Driver's list has prices all below $20,000; MotorTrend includes two of the ten with prices between $20,000 and $21,000. In addition, these vehicles appear to be gaining more content, such as improved entertainment systems and electric windows; they may be developing an identity as a desirable market segment without regard to their historic role in enabling the sales of less efficient vehicles and compliance with CAFE standards.[95] Both MotorTrend and Car and Driver note that these vehicles come with the latest safety, comfort, and entertainment features. It may be that the small, fuel-efficient vehicles previously sold with low prices are evolving to fit consumer demand that prefers content to low prices.

In sum, the low-priced vehicle segment still exists. Whether it continues to exist, and in what form, may depend on the marketing plans of manufacturers: whether benefits are greater from offering basic new vehicles to first-time new-vehicle buyers, or from making small vehicles more attractive by adding more desirable features to them.

8.4.5 Effects of Electric Vehicles on Affordability

Electric vehicles create some novel questions for affordability. Their up-front costs tend to be higher than those of comparable gasoline vehicles, and their operating costs tend to be much lower. Qualitatively, these characteristics are similar to gasoline vehicles subject to the standards, as discussed above. In addition, though, electric vehicles require access to charging. Home charging can be very convenient but requires the ability to park where charging is available; a number of people, such as those who rely on on-street parking, may not have such access. On the other hand, a recent report from the National Renewable Energy Laboratory estimated recently that the number of public and workplace charging stations is keeping up with projected needs, based on Level 2 and fast charging stations per plug-in EV.[96] As discussed in Chapter 4.1.3 under this rule the penetration of plug-in electric vehicles is projected to increase, from 7 percent in MY 2023 to 17 percent in MY 2026. EPA plans to continue to study and monitor these concerns as the prevalence of electric vehicles increases.

8.4.6 Summary of Affordability and Equity Effects

As with the effects of the standards on vehicle sales discussed in Chapter 8.1, the effects of the standards on affordability depend on two countervailing effects: the increase in the up-front costs of the vehicles, and the decrease in operating costs. The increase in up-front costs has the potential to increase the prices of used vehicles, to make credit more difficult to obtain, and to make the least expensive new vehicles less desirable compared to used vehicles. The reduction in operating costs has the potential to mitigate or reverse all these effects. Lower operating costs on their own increase mobility (see Chapter 3 for a discussion of rebound driving).

The effects of the standards on lower-income households are of great importance for social equity and reflect these contrasting forces. The overall effects of the standards on vehicle ownership, including for lower-income communities, depend heavily, as discussed in Chapter 8.1, on the role of fuel consumption in vehicle sales decisions. At the same time, lower-income households own fewer vehicles per household and are more likely to buy used vehicles than new compared to higher-income households, and they spend a higher proportion of their income on fuel than do higher-income households. As a result, lower-income households may benefit more from the reduction in operating costs than the increase in up-front costs of either new or used vehicles. Finally, we note that effects on social equity involve impacts beyond those on lower-income households. EPA will continue to examine these impacts.

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Chapter 9: Small Business Flexibilities

The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice-and-comment rulemaking requirements under the Administrative Procedure Act or any other statute. As a part of this analysis, an agency is directed to convene a Small Business Advocacy Review Panel (SBAR Panel or 'the Panel'), unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. During such a Panel process, the agency would gather information and recommendations from Small Entity Representatives (SERs) on how to reduce the impact of the rule on small entities. As discussed below, EPA is certifying that this rule will not have a significant economic impact on a substantial number of small entities, and thus we have not conducted an SBAR Panel for this final rulemaking.

The following discussion provides an overview of small entities in the vehicle market. Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration's (SBA) size standards (see Table 9-1); (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field. This chapter provides an overview of the primary SBA small business categories potentially affected by this regulation.

Table 9-1: Primary Vehicle SBA Small Business Categories

Industry [a]	Defined as Small Entity by SBA if Less Than or Equal to:	NAICS Codes [b]
Vehicle manufacturers (including small volume manufacturers)	1,500 employees	336111, 336112
Independent commercial importers	$8 million annual sales $27 million annual sales 250 employees	811111, 811112, 811198 441120 423110
Alternative Fuel Vehicle Converters	1,000 employees 1,250 employees $8 million annual sales	336312, 336322, 336399 335312 811198
Notes: a. Light-duty vehicle entities that qualify as small businesses are not be subject to this rule. We are exempting small business entities from the GHG standards. b. North American Industrial Classification System		

We compiled a list of vehicle manufacturers, independent commercial importers (ICIs), and alternative fuel converters that would be potentially affected by the rule from our 2019 and 2021 model year certification databases. These companies are already certifying their vehicles for compliance with applicable EPA emissions standards (e.g., Tier 3). We then identified companies that appear to meet the definition of small business provided in the table above. We were able to identify companies based on certification information and previous rulemakings where we conducted Regulatory Flexibility Analyses.

Based on this assessment, EPA identified a total of about 19 entities that appear to fit the Small Business Administration (SBA) criterion of a small business. EPA estimates there are about 7 small vehicle manufacturers, 4 independent commercial importers (ICIs), and 8 alternative fuel vehicle converters in the light-duty vehicle market which may qualify as small businesses (see Table 9-2 for a list of current entities). Independent commercial importers (ICIs) are companies that hold a Certificate (or Certificates) of Conformity permitting them to import nonconforming vehicles and to modify these vehicles to meet U.S. emission standards. ICIs are not required to meet the emission standards in effect when the vehicle is modified, but instead they must meet the emission standards in effect when the vehicle was originally produced (with an annual production cap of a total of 50 light-duty vehicles and trucks). Alternative fuel vehicle converters are businesses that convert gasoline or diesel vehicles to operate on alternative fuel (e.g., compressed natural gas), and converters must seek a certificate for all of their vehicle models. Model year 1993 and newer vehicles that are converted are required to meet the standards applicable at the time the vehicle was originally certified. Converters serve a niche market, and these businesses primarily convert vehicles to operate on compressed natural gas (CNG) and liquefied petroleum gas (LPG), on a dedicated or dual fuel basis.

Table 9-2: Small Business Entities

Small Vehicle Manufacturers	Alternative Fuel Convertors	Independent Commercial Importers
Ineos Automotive	AGA Systems, LLC	DRPC, LLC
Karma Automotive	Agility Powertrain Systems, LLC	G&K Automotive Conversions, Inc
Koenigsegg	Altech-Eco Corporation	Wallace Environmental Testing Laboratories, Inc
Pagani	Blossman Services, Inc.	JK Technologies, LLC
RUF	Eco Vehicle Systems, LLC	
Workhorse Group	Encore TEC LLC	
Rimac	Landi Renzo USA Corporation	
	Westport Dallas, Inc	

EPA is exempting from the GHG standards any manufacturer, domestic or foreign, meeting SBA's size definitions of small business as described in 13 CFR 121.201. EPA adopted the same type of exemption for small businesses in the MY 2012-2016 rulemaking.[1] Together, we estimate that small entities comprise less than 0.1 percent of total annual vehicle sales and exempting them will have a negligible impact on the GHG emissions reductions from the standards. In light of our exempting small businesses from the GHG standards, we are certifying in the preamble to the final rule that the rule will not have a significant economic impact on a substantial number of small entities. Therefore, EPA has not conducted a Regulatory Flexibility Analysis or a SBREFA SBAR Panel for the rule.

EPA allows small businesses to voluntarily waive their small business exemption and optionally certify to the GHG standards. This will allow small entity manufacturers to earn CO_2 credits under the GHG program, if their actual fleetwide CO_2 performance is better than their fleetwide CO_2 target standard. Manufacturers waiving their small business exemption are required to meet all aspects of the GHG standards and program requirements across their entire product line. However, the exemption waiver is optional for small entities and thus we believe that manufacturers would only opt into the GHG program if it is economically advantageous for them to do so, for example to generate and sell CO_2 credits. Therefore, EPA believes having this voluntary option does not affect EPA's determination that the standards will impose no significant adverse impact on a substantial number of small entities.

References for Chapter 9

[1] 75 FR 25424, May 7, 2010.

Chapter 10: Summary of Costs and Benefits

This chapter presents a summary of costs, benefits, and net benefits of the final program and the alternatives. This rule is not expected to have measurable inflationary or recessionary effects.

10.1 Final Rule

Table 10-1 shows the estimated annual monetized costs of the final program for the indicated calendar years. The table also shows the present values (PV) of those costs for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.[56] The table includes an estimate of foregone consumer sales surplus, which measures the loss in benefits attributed to consumers who would have purchased a new vehicle in the absence of the proposed standards.

Table 10-1: Costs Associated with the Final Program ($Billions of 2018 dollars)

Calendar Year	Foregone Consumer Sales Surplus [1]	Technology Costs	Congestion	Noise	Fatality Costs	Non-fatal Crash Costs	Total Costs
2023	$0.029	$5.6	$0.03	$0.00045	$0.13	$0.23	$6.1
2026	$0.11	$16	$0.12	$0.002	$0.42	$0.7	$17
2030	$0.093	$17	$0.4	$0.0067	$0.44	$0.73	$19
2035	$0.078	$17	$0.68	$0.011	$0.27	$0.44	$19
2040	$0.063	$16	$0.84	$0.014	$0.15	$0.25	$17
2050	$0.052	$15	$0.9	$0.015	$0.16	$0.25	$16
PV, 3%	$1.3	$280	$9.6	$0.16	$4.9	$8.1	$300
PV, 7%	$0.84	$160	$4.8	$0.08	$3.2	$5.3	$180
Annualized, 3%	$0.069	$14	$0.49	$0.0082	$0.25	$0.42	$15
Annualized, 7%	$0.068	$13	$0.39	$0.0065	$0.26	$0.43	$14

[1] "Foregone Consumer Sales Surplus" refers to the difference between a vehicle's price and the buyer's willingness to pay for the new vehicle; the impact reflects the reduction in new vehicle sales described in Chapter8.1. See Section 8 of CAFE_Model_Documentation_FR_2020.pdf in the docket for more information.

Table 10-2 shows the undiscounted annual monetized fuel savings of the program. The table also shows the present value of those fuel savings for the same calendar years using both 3 percent and 7 percent discount rates. The aggregate value of fuel savings is calculated using pre-tax fuel prices since savings in fuel taxes do not represent a reduction in the value of economic resources utilized in producing and consuming fuel. Note that the fuel savings shown in Table 10-2 result from reductions in fleet-wide fuel use and include rebound effects, credit usage and advanced technology multiplier use. Thus, fuel savings grow over time as an increasing fraction of the fleet is projected to meet the final standards.

[56] For the estimation of the stream of costs and benefits, we assume that after implementation of the proposed MY 2023-2026 standards, the 2026 standards apply to each year thereafter.

Table 10-2: Fuel Savings Associated with the Final Program ($Billions of 2018 dollars)

Calendar Year	Retail Fuel Savings	Fuel Tax Savings	Total Fuel Savings
2023	$0.94	$0.31	$0.62
2026	$5.1	$1.7	$3.3
2030	$16	$4.5	$12
2035	$28	$7.1	$21
2040	$37	$8.5	$29
2050	$42	$8.6	$33
PV, 3%	$420	$100	$320
PV, 7%	$210	$51	$150
Annualized, 3%	$21	$5.1	$16
Annualized, 7%	$17	$4.1	$12
Table Note: Electricity expenditure increases are included.			

Table 10-3 presents estimated annual monetized benefits from non-emission sources for the indicated calendar years. The table also shows the present value of those benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.

Table 10-3: Benefits from Non-Emission Sources for the Final Rule ($Billions of 2018 dollars)

Calendar Year	Drive Value	Refueling Time Savings	Energy Security Benefits	Total Non-Emission Benefits
2023	$0.035	-$0.0052	$0.031	$0.061
2026	$0.14	-$0.12	$0.18	$0.2
2030	$0.55	-$0.27	$0.51	$0.79
2035	$1	-$0.47	$0.92	$1.5
2040	$1.3	-$0.67	$1.3	$1.9
2050	$1.5	-$0.83	$1.6	$2.3
PV, 3%	$15	$-7.4	$14	$21
PV, 7%	$7.2	$-3.6	$7	$11
Annualized, 3%	$0.75	$-0.38	$0.73	$1.1
Annualized, 7%	$0.58	$-0.29	$0.56	$0.85

Table 10-4 presents estimated annual monetized benefits from emission sources for the indicated calendar years. The table also shows the present value of those benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.

Table 10-5 shows the benefits of reduced GHG emissions, and consequently the annual quantified benefits (i.e., total GHG benefits), for each of the four interim social cost of GHG (SC-GHG) values estimated by the interagency working group. As discussed in RIA Chapter 3.3 there are some limitations to the SC-GHG analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

Table 10-4: $PM_{2.5}$-related Emission Reduction Benefits of the Final Rule ($Billions of 2018 dollars)

Calendar Year	Tailpipe Benefits		Upstream Benefits		Total $PM_{2.5}$-related Benefits	
	3% DR	7% DR	3% DR	7% DR	3% DR	7% DR
2023	-$0.0034	-$0.0031	$0.02	$0.018	$0.016	$0.015
2026	$0.018	$0.016	$0.097	$0.088	$0.11	$0.1
2030	$0.15	$0.13	$0.45	$0.41	$0.6	$0.54
2035	$0.44	$0.4	$0.79	$0.72	$1.2	$1.1
2040	$0.68	$0.62	$1	$0.95	$1.7	$1.6
2050	$0.89	$0.8	$1.4	$1.3	$2.3	$2.1
PV	$6.7	$2.8	$12	$5.3	$19	$8.1
Annualized	$0.34	$0.22	$0.61	$0.43	$0.96	$0.65

Notes:
[a] Note that the non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.
[b] Calendar year non-GHG benefits presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of PM-related premature mortality to account for a twenty-year segmented cessation lag. Note that annual benefits estimated using a 3 percent discount rate were used to calculate the present and annualized values using a 3 percent discount rate and the annual benefits estimated using a 7 percent discount rate were used to calculate the present and annualized values using a 7 percent discount rate.

Table 10-5: Climate Benefits from Reduction in GHG Emissions ($Billions of 2018 dollars)

Calendar Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.081	$0.27	$0.4	$0.8
2026	$0.48	$1.6	$2.3	$4.7
2030	$1.5	$4.6	$6.7	$14
2035	$2.8	$8.4	$12	$25
2040	$3.9	$11	$16	$34
2050	$5.5	$14	$20	$44
PV	$31	$130	$200	$390
Annualized	$2	$6.6	$9.5	$20

Notes:
Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.
The same discount rate used to discount the value of damages from future emissions (SC-GHGs at 5, 3, 2.5 percent) is used to calculate the present value of SC-GHGs for internal consistency Annual benefits shown are undiscounted values.

Table 10-6 presents estimated annual net benefits for the indicated calendar years. The table also shows the present value of those net benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates. The table includes the benefits of reduced GHG emissions (and consequently the annual net benefits) for each of the four SC-GHG values considered by EPA. We estimate that the proposed program would result in a net present value of benefits that ranges between $27-$450 billion; that is, the total benefits would far exceed the costs of the program.

Table 10-6: Net Benefits (Emission Benefits + Non-Emission Benefits + Fuel Savings – Costs) Associated with the Final Program ($Billions of 2018 dollars)

Calendar Year	Net Benefits, with Climate Benefits based on 5% discount rate	Net Benefits, with Climate Benefits based on 3% discount rate	Net Benefits, with Climate Benefits based on 2.5% discount rate	Net Benefits, with Climate Benefits based on 3% discount rate, 95th percentile SC-GHG
2023	-$5.3	-$5.1	-$5	-$4.6
2026	-$13	-$12	-$11	-$9.1
2030	-$4.6	-$1.4	$0.63	$7.9
2035	$7.8	$13	$17	$30
2040	$19	$26	$31	$49
2050	$27	$36	$41	$66
PV, 3%	$88	$190	$260	$450
PV, 7%	$27	$120	$190	$390
Annualized, 3%	$4.9	$9.5	$12	$23
Annualized, 7%	$1.7	$6.2	$9.2	$20

Notes:
Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts. The same discount rate used to discount the value of damages from future emissions (SC-GHG at 5, 3, 2.5 percent) is used to calculate present value of SC-GHGs for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent. Annual costs and benefits shown are undiscounted values. Note that the non-GHG impacts associated with the standards included here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

10.2 Comparison to Proposal (Less Stringent Alternative)

The same series of tables as presented in Chapter 10.1 for the final standards are presented here for the Proposal. Note that Table 10-7 includes an estimate of foregone consumer sales surplus, which measures the loss in benefits attributed to consumers who would have purchased a new vehicle in the absence of the proposed standards.

Table 10-7: Costs Associated with the Proposal ($Billions of 2018 dollars)

Calendar Year	Foregone Consumer Sales Surplus[1]	Technology Costs	Congestion	Noise	Fatality Costs	Non-fatal Crash Costs	Total Costs
2023	$0.025	$4.7	$0.014	$0.00021	$0.11	$0.18	$5
2026	$0.061	$10	$0.086	$0.0014	$0.32	$0.54	$11
2030	$0.046	$11	$0.3	$0.0049	$0.28	$0.46	$12
2035	$0.038	$11	$0.5	$0.0082	$0.16	$0.27	$12
2040	$0.031	$9.7	$0.61	$0.0099	$0.089	$0.14	$11
2050	$0.025	$9.1	$0.65	$0.011	$0.072	$0.12	$9.9
PV, 3%	$0.72	$170	$7	$0.11	$3.2	$5.3	$190
PV, 7%	$0.46	$100	$3.5	$0.057	$2.1	$3.5	$110
Annualized, 3%	$0.037	$8.9	$0.35	$0.0058	$0.16	$0.27	$9.8
Annualized, 7%	$0.037	$8.4	$0.28	$0.0046	$0.17	$0.29	$9.2

Notes:
[1] "Foregone Consumer Sales Surplus" refers to the difference between a vehicle's price and the buyer's willingness to pay for the new vehicle; the impact reflects the reduction in new vehicle sales described in Chapter 8.1. See Section 8 of CAFE_Model_Documentation_FR_2020.pdf in the docket for more information.

Table 10-8 shows the undiscounted annual monetized fuel savings of the Proposal. The table also shows the present value of those fuel savings for the same calendar years using both 3 percent and 7 percent discount rates. The aggregate value of fuel savings is calculated using pre-tax fuel prices since savings in fuel taxes do not represent a reduction in the value of economic resources utilized in producing and consuming fuel. Note that the fuel savings shown in Table 10-8 result from reductions in fleet-wide fuel use. Thus, fuel savings grow over time as an increasing fraction of the fleet is projected to meet the standards.

Table 10-8: Fuel Savings Associated with the Proposal ($Billions of 2018 dollars)

Calendar Year	Retail Fuel Savings	Fuel Tax Savings	Total Fuel Savings
2023	$0.62	$0.23	$0.39
2026	$3.5	$1.2	$2.3
2030	$11	$3	$7.7
2035	$18	$4.6	$14
2040	$24	$5.4	$18
2050	$27	$5.5	$22
PV, 3%	$270	$65	$210
PV, 7%	$130	$33	$100
Annualized, 3%	$14	$3.3	$11
Annualized, 7%	$11	$2.7	$8.2

Table 10-9 presents estimated annual monetized benefits from non-emission sources for the indicated calendar years. The table also shows the present value of those benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.

Table 10-9: Benefits from Non-Emission Sources Associated with the Proposal ($Billions of 2018 dollars)

Calendar Year	Drive Value	Refueling Time Savings	Energy Security Benefits	Total Non-Emission Benefits
2023	$0.013	-$0.019	$0.023	$0.017
2026	$0.085	-$0.12	$0.13	$0.094
2030	$0.38	-$0.19	$0.34	$0.54
2035	$0.72	-$0.29	$0.6	$1
2040	$0.93	-$0.34	$0.81	$1.4
2050	$1	-$0.49	$1	$1.6
PV, 3%	$10	$-4.4	$9.3	$15
PV, 7%	$5	$-2.3	$4.6	$7.3
Annualized, 3%	$0.52	$-0.22	$0.47	$0.77
Annualized, 7%	$0.4	$-0.18	$0.37	$0.59

Table 10-10 presents estimated annual monetized benefits from emission sources for the indicated calendar years. The table also shows the present value of those benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.

Table 10-10: $PM_{2.5}$-related Emission Reduction Benefits Associated with the Proposal ($Billions of 2018 dollars)

Calendar Year	Tailpipe Benefits		Upstream Benefits		Total $PM_{2.5}$-related Benefits	
	3% DR	7% DR	3% DR	7% DR	3% DR	7% DR
2023	-$0.0023	-$0.0021	$0.0017	$0.0016	-$0.00061	-$0.00053
2026	$0.012	$0.011	$0.048	$0.045	$0.061	$0.056
2030	$0.1	$0.094	$0.29	$0.27	$0.4	$0.36
2035	$0.29	$0.26	$0.52	$0.47	$0.81	$0.73
2040	$0.43	$0.39	$0.68	$0.62	$1.1	$1
2050	$0.56	$0.51	$0.91	$0.82	$1.5	$1.3
PV	$4.3	$1.8	$7.7	$3.4	$12	$5.2
Annualized	$0.22	$0.14	$0.39	$0.27	$0.61	$0.42

Notes:
[a] Note that the non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.
[b] Calendar year non-GHG benefits presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of PM-related premature mortality to account for a twenty-year segmented cessation lag. Note that annual benefits estimated using a 3 percent discount rate were used to calculate the present and annualized values using a 3 percent discount rate and the annual benefits estimated using a 7 percent discount rate were used to calculate the present and annualized values using a 7 percent discount rate.

Table 10-11 shows the benefits of reduced GHG emissions, and consequently the annual quantified benefits (i.e., total benefits), for each of the four interim social cost of GHG (SC-GHG) values estimated by the interagency working group. As discussed in RIA Chapter 3.3 there are some limitations to the SC-GHG analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

Table 10-11: Climate Benefits from Reduction in Greenhouse Gas Emissions Associated with the Proposal ($Billions of 2018 dollars)

Calendar Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.055	$0.18	$0.27	$0.55
2026	$0.34	$1.1	$1.6	$3.3
2030	$0.99	$3.1	$4.5	$9.3
2035	$1.8	$5.5	$7.8	$17
2040	$2.5	$7.2	$10	$22
2050	$3.5	$9.2	$13	$28
PV	$20	$83	$130	$250
Annualized	$1.3	$4.3	$6.2	$13

Notes:
Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.
The same discount rate used to discount the value of damages from future emissions (SC-GHGs at 5, 3, 2.5 percent) is used to calculate the present value of SC-GHGs for internal consistency Annual benefits shown are undiscounted values.

Table 10-12 presents estimated annual net benefits for the indicated calendar years. The table also shows the present value of those net benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates. The table includes the benefits of reduced GHG emissions (and consequently the annual net benefits) for each of the four SC-GHG values considered by EPA.

Table 10-12: Net Benefits (Emission Benefits + Non-Emission Benefits + Fuel Savings – Costs) for the Proposal ($Billions of 2018 dollars)

Calendar Year	Net Benefits, with Climate Benefits based on 5% discount rate	Net Benefits, with Climate Benefits based on 3% discount rate	Net Benefits, with Climate Benefits based on 2.5% discount rate	Net Benefits, with Climate Benefits based on 3% discount rate, 95th percentile SC-GHG
2023	-$4.6	-$4.4	-$4.3	-$4.1
2026	-$8.6	-$7.8	-$7.3	-$5.7
2030	-$2.2	-$0.077	$1.3	$6.2
2035	$5.9	$9.5	$12	$21
2040	$13	$18	$20	$32
2050	$18	$24	$27	$43
PV, 3%	$62	$130	$170	$300
PV, 7%	$19	$82	$130	$250
Annualized, 3%	$3.5	$6.4	$8.3	$15
Annualized, 7%	$1.2	$4.2	$6.1	$13

Notes:
a Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts. The same discount rate used to discount the value of damages from future emissions (SC-GHG at 5, 3, 2.5 percent) is used to calculate present value of SC-GHGs for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent. Annual costs and benefits shown are undiscounted values.

10.3 Comparison to the More Stringent Alternative 2 Minus 10

The same series of tables as presented in Chapter 10.1 for the final standards are presented here for the more stringent standards, referred to as Alternative 2 minus 10. Note that Table 10-13 includes an estimate of foregone consumer sales surplus, which measures the loss in benefits attributed to consumers who would have purchased a new vehicle in the absence of the standards.

Table 10-13: Costs Associated with the Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Foregone Consumer Sales Surplus [1]	Technology Costs	Congestion	Noise	Fatality Costs	Non-fatal Crash Costs	Total Costs
2023	$0.06	$10	$0.051	$0.0008	$0.24	$0.4	$11
2026	$0.12	$17	$0.18	$0.0029	$0.5	$0.83	$19
2030	$0.096	$18	$0.45	$0.0076	$0.46	$0.75	$19
2035	$0.081	$17	$0.72	$0.012	$0.25	$0.41	$19
2040	$0.066	$16	$0.86	$0.014	$0.13	$0.22	$17
2050	$0.054	$15	$0.9	$0.015	$0.13	$0.21	$16
PV, 3%	$1.5	$290	$10	$0.17	$5.3	$8.7	$320
PV, 7%	$0.94	$180	$5.2	$0.088	$3.6	$5.9	$190
Annualized, 3%	$0.075	$15	$0.52	$0.0087	$0.27	$0.44	$16
Annualized, 7%	$0.076	$14	$0.42	$0.0071	$0.29	$0.48	$15

[1] "Foregone Consumer Sales Surplus" refers to the difference between a vehicle's price and the buyer's willingness to pay for the new vehicle; the impact reflects the reduction in new vehicle sales described in Chapter 8.1. See Section 8 of CAFE_Model_Documentation_FR_2020.pdf in the docket for more information.

Table 10-14 shows the undiscounted annual monetized fuel savings of Alternative 2 minus 10. The table also shows the present value of those fuel savings for the same calendar years using both 3 percent and 7 percent discount rates. The aggregate value of fuel savings is calculated using pre-tax fuel prices since savings in fuel taxes do not represent a reduction in the value of economic resources utilized in producing and consuming fuel. Note that the fuel savings shown in Table 10-14 result from reductions in fleet-wide fuel use. Thus, fuel savings grow over time as an increasing fraction of the fleet is projected to meet the standards.

Table 10-14: Fuel Savings Associated with Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Retail Fuel Savings	Fuel Tax Savings	Total Fuel Savings
2023	$1.4	$0.47	$0.94
2026	$6	$2	$4
2030	$17	$4.7	$12
2035	$29	$7.3	$21
2040	$37	$8.5	$29
2050	$42	$8.7	$33
PV, 3%	$430	$100	$320
PV, 7%	$210	$53	$160
Annualized, 3%	$22	$5.2	$16
Annualized, 7%	$17	$4.2	$13

Table 10-15 presents estimated annual monetized benefits from non-emission sources for the indicated calendar years. The table also shows the present value of those benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.

Table 10-15: Benefits from Non-Emission Sources Associated with Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Drive Value	Refueling Time Savings	Energy Security Benefits	Total Non-Emission Benefits*
2023	$0.06	-$0.015	$0.047	$0.092
2026	$0.22	-$0.094	$0.21	$0.33
2030	$0.63	-$0.27	$0.54	$0.9
2035	$1.1	-$0.45	$0.94	$1.6
2040	$1.4	-$0.55	$1.3	$2.1
2050	$1.5	-$0.86	$1.6	$2.3
PV, 3%	$16	$-6.7	$15	$24
PV, 7%	$7.9	$-3.3	$7.2	$12
Annualized, 3%	$0.81	$-0.34	$0.75	$1.2
Annualized, 7%	$0.64	$-0.27	$0.58	$0.95

Table 10-16 presents estimated annual monetized benefits from emission sources for the indicated calendar years. The table also shows the present value of those benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates.

Table 10-16: $PM_{2.5}$-related Emission Reduction Benefits Associated with Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Tailpipe Benefits		Upstream Benefits		Total $PM_{2.5}$-related Benefits	
	3% DR	7% DR	3% DR	7% DR	3% DR	7% DR
2023	-$0.0076	-$0.0068	$0.031	$0.028	$0.023	$0.021
2026	$0.018	$0.016	$0.15	$0.13	$0.17	$0.15
2030	$0.16	$0.14	$0.5	$0.45	$0.66	$0.6
2035	$0.46	$0.42	$0.81	$0.74	$1.3	$1.2
2040	$0.71	$0.64	$1.1	$0.95	$1.8	$1.6
2050	$0.93	$0.84	$1.4	$1.3	$2.3	$2.1
PV	$7	$2.9	$12	$5.5	$19	$8.4
Annualized	$0.36	$0.23	$0.63	$0.45	$0.99	$0.68

Notes:
[a] Note that the non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.
[b] Calendar year non-GHG benefits presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of PM-related premature mortality to account for a twenty-year segmented cessation lag. Note that annual benefits estimated using a 3 percent discount rate were used to calculate the present and annualized values using a 3 percent discount rate and the annual benefits estimated using a 7 percent discount rate were used to calculate the present and annualized values using a 7 percent discount rate.

Table 10-17 shows the benefits of reduced GHG emissions, and consequently the annual quantified benefits (i.e., total benefits), for each of the four interim social cost of GHG (SC-GHG) values estimated by the interagency working group. As discussed in RIA Chapter 3.3 there are some limitations to the SC-GHG analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

Table 10-17: Climate Benefits from Reduction in Greenhouse Gas Emissions Associated with Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2023	$0.12	$0.41	$0.6	$1.2
2026	$0.56	$1.8	$2.7	$5.5
2030	$1.6	$4.9	$7.1	$15
2035	$2.9	$8.6	$12	$26
2040	$3.9	$11	$16	$34
2050	$5.5	$14	$20	$44
PV	$32	$130	$200	$400
Annualized	$2.1	$6.7	$9.7	$20

Notes:
Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.
The same discount rate used to discount the value of damages from future emissions (SC-GHGs at 5, 3, 2.5 percent) is used to calculate the present value of SC-GHGs for internal consistency Annual benefits shown are undiscounted values.

Table 10-18 presents estimated annual net benefits for the indicated calendar years. The table also shows the present value of those net benefits for the calendar years 2021-2050 using both 3 percent and 7 percent discount rates. The table includes the benefits of reduced GHG emissions (and consequently the annual net benefits) for each of the four SC-GHG values considered by EPA.

Table 10-18: Net Benefits (Emission Benefits + Non-Emission Benefits + Fuel Savings – Costs) Associated with Alternative 2 minus 10 ($Billions of 2018 dollars)

Calendar Year	Net Benefits, with Climate Benefits based on 5% discount rate	Net Benefits, with Climate Benefits based on 3% discount rate	Net Benefits, with Climate Benefits based on 2.5% discount rate	Net Benefits, with Climate Benefits based on 3% discount rate, 95th percentile SC-GHG
2023	-$9.6	-$9.3	-$9.1	-$8.5
2026	-$14	-$12	-$12	-$8.8
2030	-$4.1	-$0.77	$1.4	$9.1
2035	$8.1	$14	$17	$31
2040	$19	$26	$31	$49
2050	$27	$36	$41	$65
PV, 3%	$80	$180	$250	$450
PV, 7%	$19	$120	$190	$390
Annualized, 3%	$4.5	$9.2	$12	$23
Annualized, 7%	$1.1	$5.7	$8.7	$19

Notes:
Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four SC-CO_2, SC-CH_4, and SC-N_2O estimates. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts. The same discount rate used to discount the value of damages from future emissions (SC-GHG at 5, 3, 2.5 percent) is used to calculate present value of SC-GHGs for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent. Annual costs and benefits shown are undiscounted values.

10.4 Sensitivities

We have conducted the following sensitivities:

- AEO high oil price (AEO high)
- AEO low oil price (AEO low)
- Allow HCR2 in MY 2025 and later (Allow HCR2)
- Battery costs higher (uses NPRM battery costs)
- Battery costs lower (battery costs roughly 24 percent lower than the updated FRM costs)
- Sales demand elasticity of -0.15
- Sales demand elasticity of -1.0
- Mass safety coefficients at the 5th percentile (Mass safety 5th pctile)
- Mass safety coefficients at the 95th percentile (Mass safety 95th pctile)
- No further applicaton of mild or string hybrid technology (no hybrids)
- Perfect trading, which allows perfect trading of CO_2 credits between manufacturers[57]

[57] To simulate perfect trading, the entire fleet is attributed to a single manufacturer, dubbed "Industry," in the market input file.

- Rebound rate of -5 percent
- Rebound rate of -15 percent

Each sensitivity is compared to its own no action scenario. In other words, the no action standards were used but the no action scenario was run using the same set of sensitivity parameters as used for the action scenario.

Table 10-19 Monetized Discounted Costs, Benefits, and Net Benefits of the Proposed Program and each Sensitivity for Calendar Years through 2050 ($Billions of 2018 dollars, 3 percent Discount Rate)[a,b,c,d]

	Final	AEO High	AEO Low	Allow HCR2	Higher Battery Costs	Lower Battery Costs	Demand elast. of -0.15	Demand elast. of -1.0	Mass safety at 5th pctile	Mass safety at 95 pctile	No Hybrids	Perfect Trading	Rebound of 15%	Rebound of 5%
Costs	$300	$260	$330	$300	$360	$240	$300	$300	$280	$320	$310	$330	$310	$290
Fuel Savings	$320	$510	$170	$320	$330	$310	$320	$310	$320	$320	$310	$360	$320	$320
Benefits	$170	$150	$190	$170	$190	$160	$170	$170	$170	$170	$160	$190	$180	$160
Net Benefits	$190	$400	$30	$190	$150	$230	$190	$180	$210	$160	$160	$220	$190	$190

Notes:

a Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.

b Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate, but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

c The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.

d Net benefits reflect the fuel savings plus benefits minus costs.

e Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.

Table 10-20 Monetized Discounted Costs, Benefits, and Net Benefits of the Proposed Program and each Sensitivity for Calendar Years through 2050 ($Billions of 2018 dollars, 7 percent Discount Rate)[a,b,c,d]

	Final	AEO High	AEO Low	Allow HCR2	Higher Battery Costs	Lower Battery Costs	Demand elast. of -0.15	Demand elast. of -1.0	Mass safety at 5th pctile	Mass safety at 95 pctile	No Hybrids	Perfect Trading	Rebound of 15%	Rebound of 5%
Costs	$180	$160	$190	$180	$220	$150	$180	$180	$170	$190	$180	$190	$180	$170
Fuel Savings	$150	$250	$83	$160	$160	$150	$160	$150	$150	$150	$150	$170	$150	$160
Benefits	$150	$130	$170	$150	$160	$140	$150	$150	$150	$150	$140	$170	$150	$140
Net Benefits	$130	$230	$55	$130	$95	$150	$130	$120	$140	$110	$110	$150	$120	$120

Notes:

a Values rounded to two significant figures; totals may not sum due to rounding. Present and annualized values are based on the stream of annual calendar year costs and benefits included in the analysis (2021 – 2050) and discounted back to year 2021.

b Climate benefits are based on reductions in CO_2, CH4 and N2O emissions and are calculated using four different estimates of the social cost of each greenhouse gas (SC-GHG model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate), which each increase over time. For the presentational purposes of this table, we show the benefits associated with the average SC-GHGs at a 3 percent discount rate, but the Agency does not have a single central SC-GHG point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-GHG estimates and present them later in this RIA. As discussed in Chapter 3.3 of the RIA, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

c The same discount rate used to discount the value of damages from future GHG emissions (SC-GHGs at 5, 3, and 2.5 percent) is used to calculate the present and annualized values of climate benefits for internal consistency, while all other costs and benefits are discounted at either 3 percent or 7 percent.

d Net benefits reflect the fuel savings plus benefits minus costs.

e Non-GHG impacts associated with the standards presented here do not include the full complement of health and environmental effects that, if quantified and monetized, would increase the total monetized benefits. Instead, the non-GHG benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure.